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CONTENTS

The Relationship of Anxiety to the Conditioned Eyelid Response: JANET A. TAYLOR 81

New Gradients of Error Reinforcement in Multiple-Choice Human Learning: M. H. MARX AND M. E. BUNCH 93

The Effect of Reinforcement on the Alternation of Guesses: A. W. BENDIG 105

The Perception of the Vertical: V. Adjustment to the Postural Vertical as a Function of the Magnitude of Postural Tilt and Duration of Exposure: C. W. MANN AND G. E. PASSEY 108

Post-rotational Perception of Apparent Bodily Rotation: C. W. MANN, F. E. GUEDRY, AND J. T. RAY 114

The Negative Effect of Previous Experience on Productive Thinking: H. G. BIRCH AND H. S. RABINOWITZ 121

Pursuit Learning as Affected by Size of Target and Speed of Rotation: J. S. HELMICK 126

Electroretinal and Psychophysical Dark Adaptation Curves: E. P. JOHNSON AND L. A. RIGGS 139

Response Evocation on Satiated Trials in the T-Maze: K. TEEL AND W. B. WEBB 148

Color Adaptation under Conditions of Homogeneous Visual Stimulation (Ganzfeld): J. E. HOCHBERG, W. TRIEBEL, AND G. SEAMAN 153

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THE RELATIONSHIP OF ANXIETY TO THE CONDITIONED EYELID RESPONSE [1]

BY JANET A. TAYLOR [2]
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A number of contemporary psychological theorists, such as Hull (2), Tolman (9), and Lewin (5), are in agreement that behavior is a function of two principle classes of variables: learning or cognitive on the one hand, and motivation on the other. These classes of variables are further conceived by Hull (2) as combining according to some multiplicative function, implying that a zero value of either will lead to failure of response occurrence. Hull has specifically proposed the following:

$$R = f({}_sE_R) = f\frac{({}_sH_R \times D)}{100}$$

where R = response measure (e.g., latency, frequency of response)

${}_sE_R$ = excitatory potential, a theoretical construct

${}_sH_R$ = habit strength, a theoretical construct

D = drive strength, a theoretical construct.

In Hull's formulations, ${}_sH_R$ represents the hypothetical learning factor resulting from the operation of such experimental variables as the number and amount of reinforcements, etc. The hypothetical construct D represents the total effective drive strength operating in the organism at a given moment. Thus, in a particular experimental situation, the value of D is assumed to be determined not only by the relevant need (i.e., the one which is reduced by the response under consideration) but also by the aggregate strength of all other primary and secondary needs operative at the moment. These latter are referred to as irrelevant needs. Needs, in turn, are a function of certain antecedant conditions (e.g., environmental deficiencies, noxious stimulation).

There is now available concrete evidence supporting the chief implications of Hull's assumption that needs combine to produce drive

[1] This article is based on a dissertation submitted to the faculty of the Department of Psychology of the State University of Iowa in partial fulfillment of the requirements for the Ph.D. degree. The writer is greatly indebted to Professor Kenneth W. Spence for his criticisms and suggestions during the course of this study.

[2] Now at Northwestern University.

strength, although there is still considerable doubt concerning the precise form of the summation equation. Kendler (4), Webb (10), and Amsel (1) have all found that two needs will summate to produce a greater drive strength than will either one alone. In the Kendler and Webb studies, two appetitional needs, hunger and thirst, were involved, while in the Amsel study a hunger need was combined, in one instance, with a primary need to escape pain, and in the second instance, with a secondary need to escape anxiety.[3]

In many experimental learning situations, e.g., salivary conditioning, instrumental reward and escape learning, problem solving, etc., the drive strength is primarily a function of a relevant need, one produced by the *E*'s manipulation of a maintenance schedule or by administration of a noxious stimulus. The response to be learned leads either to the needed goal object or to escape from the noxious stimulus. A quite different situation exists, however, in the case of classical defense conditioning in which a noxious stimulus of very brief duration is administered. The identification of the drive operative at the time of the conditioned response is much more difficult in this situation. As the conditioned response anticipates the occurrence of the noxious stimulus, one cannot appeal to the latter as the direct basis of the drive.

One suggested answer to this problem is that offered by Mowrer (7). He has assumed that the drive is a secondary one, anxiety. According to his analysis, stimuli which are consistently present when a noxious stimulus occurs come to evoke an emotional response of fear in anticipation of the noxious stimulus. This anticipatory fear reaction, termed anxiety, is assumed to provide the motivational state, or drive (*D*).

Further analysis, however, suggests difficulties in this explanation which Mowrer (8) himself later considered. The fear response is mediated by the autonomic nervous system which has a longer latency and a slower rate of responding than the skeletal reactions mediated by the central nervous system. In those defense conditioning situations in which the temporal interval between onset of the conditioned and unconditioned stimulus is small, shorter than the latency of the fear response, and the unconditioned response is a skeletal reaction of short duration, the CS, UCS, and CR have all taken place *before* the fear response has occurred. Appeal to such an anxiety reaction as the motivational factor operating at the time the conditioned response occurs therefore cannot be made.

Several other possibilities can be suggested in solution of this problem. It is an oversimplification to consider that only the conditioned stimulus has become associated with the unconditioned response: the total experimental situation also becomes associated with the fear or anxiety reaction. While differentiation between total situation and total situation-plus-CS (which is followed by the noxious stimulus) may be expected to take place in the course of time, initially, at least, the anxiety level of the *S* is heightened and is therefore available as a motivator at the time of the onset of the CS. In human *S*s, a further source of anxiety would be that elicited by verbal reactions. Depending on the extent to which the emotional responses have been conditioned to verbal cues, *S*s will exhibit different amounts of anxiety.

[3] Amsel (1), following Mowrer (7) defined anxiety as the conditioned form of the pain reaction.

A further possible source of drive for the conditioned response may be the residual effects of the internal emotional response to the noxious stimulus of the preceding trial. The duration of such an emotional response is relatively long and extends beyond the range of temporal intervals usually employed in conditioning experiments. Since the effects have not worn off completely between trials, these residual effects may be cumulative and possibly serve to raise the total drive level of the *S* during the course of the experimental session.

A third suggested source of the motivation comes from the aggregate of primary and secondary needs that are, in a sense, brought to, but not specifically induced by, the experimental situation, i.e., what was referred to above as irrelevant needs. These needs are also regarded as contributing to the total drive strength (*D*) operative at the moment of the conditioned response. An investigation by Welch and Kubis (11) gives some support to these suggestions. These experimenters studied the rate of conditioning of the PGR in normal *Ss*, and in *Ss* from a hospital population diagnosed psychiatrically as exhibiting pathological anxiety. The criteria used in the selection of the anxious *Ss*, in agreement with general psychiatric thought, were behavioral symptoms which we could describe as overt manifestations of a persistently heightened emotional level. Their results indicated that there was almost no overlap between groups, the anxiety *Ss* being far superior to the normal group in reaching the conditioning criterion. The difference in mean scores of the groups was significant at a high level of confidence.

The hypothesis suggested in the present investigation is that such sources of drive as those hitherto discussed combine in some such manner as assumed by Hull to produce a total effective drive state (*D*), and that it is this drive value that determines the strength of the conditioned response in the classical defense conditioning situation.[4] In testing this hypothesis it is, of course, impossible to arrange a situation in which no drive is present at the time of occurrence of the conditioned response. If, however, differences in drive level among groups of *Ss* can be produced either experimentally or by some selection procedure, a comparison of the rate and level of development of the CR in these groups should provide data bearing on the hypothesis proposed.

Plan of Experiment

The present experiment was designed to provide data on the effect that differing levels of total effective drive would have on the development of a conditioned defense response. The rate of the development of the conditioned eyelid response was measured as a function of (1) the general anxiety (drive) level of the *S*, defined independently of the experimental situation, and (2) differential instructions, aimed at raising or lowering anxiety level, given to the *S* during the course of the conditioning trials.

An attempt was made to secure different levels of drive by two means: (1) selection of two groups of *Ss*, hereafter designated as anxious and non-anxious, on the basis of extreme scores made on a test to be described below, and (2) administration of differential instructions, designated as anxiety-producing or anxiety-relieving, introduced during the course of

[4] In terms of Hull's theory, this drive value (*D*) multiplies the learning factor (*H*) to determine the excitatory potential (*E*). Different response measures are then assumed to be a direct function of the excitatory potential value.

the conditioning trials. The effect of these two sets of variables on the development of the conditioned eyelid response was then studied.

Selection of anxious and non-anxious subjects.—On the assumption that variations in what is described psychiatrically as "manifest anxiety" reflect variations in generalized levels of drive, a test of manifest anxiety was constructed for the purpose of selecting *Ss* for the experimental groups.

Approximately two hundred items from the Minnesota Multiphasic Personality Inventory were submitted to clinical staff members with instructions to designate those items that they judged to be indicative of manifest anxiety according to a definition furnished them. The 65 items on which there was 80 per cent agreement or better were selected for the final anxiety scale.

These 65 items, supplemented by 135 additional items from the MMPI tapping some dimension other than anxiety, were administered in group form to 352 students in a course in Introductory Psychology. The measures, based only on the 65 anxiety items, ranged from a low anxiety score of 1 to a high anxiety score of 36, with a median score of 14. The form of the distribution was slightly skewed in the direction of high anxiety.

The selection of subjects for the anxious and non-anxious groups was made by taking the individuals who scored in the upper 12 and lower 9 percentiles of the distribution.[5] The raw test scores for the non-anxious group ranged from 1 to 7, and for the anxious group from 24 to 36.

It was presumed that *Ss* from the anxious end of the scale would be at a relatively higher drive level (*D*) than the *Ss* from the low end of the scale. In terms of Hull's assumptions as to the role of drive strength in determining response strength, this would imply that the anxious subjects would exhibit a relatively higher level of conditioning.

Experimental manipulation of anxiety level of subjects.—During the course of the conditioning trials, half of the *Ss* in each group was told that the intensity of the UCS would be increased on subsequent trials, although the actual intensity remained the same. The other half of each group was told that the intensity would be decreased, but again the actual intensity was kept constant. Those receiving instructions designed to heighten anxiety were designated as a plus group, while those receiving instructions aimed at lowering anxiety were designated as a minus group.

Experimental Method

Subjects.—Sixty-seven *Ss* were run in the experiment, but 7, 3 from the anxious group and 4 from the non-anxious group, did not meet certain criteria established for their performance, and for this reason, their records were excluded from the experimental results. Three of the anxious *Ss* and 1 of the non-anxious *Ss* thus eliminated exceeded the criterion determined for spontaneous blinking rate. This criterion will be discussed in a later section. Of the 3 remaining *Ss*, all in the non-anxious group, 1 was eliminated because of equipment failure, 1 because of misunderstanding of instructions, and 1 because he gave initial CR's to the CS alone, prior to paired presentation of the CS and UCS.

Of the remaining *Ss*, 30 were from the high (anxious) end of the distribution and 30 from the low (non-anxious) end.

Apparatus and method of recording.—The *S* was seated in a dental chair in a semi-darkened room adjoining that in which the recording apparatus and stimulus controls were located. Fixed in a reclining position in the chair with his

[5] All students in the introductory course are required to serve a certain number of hours as experimental *Ss*, so that no connection was made by the students between the test and their selection as *Ss*. Furthermore, each *S* was told that his name had been selected at random in order to secure a representative sample of the class.

head braced against a headrest, the *S* was instructed, on receiving a ready signal, to fixate a 6-cm. circular milk glass window, or disc, placed at a distance of 132 cm. in front of him. The brightness of the glass window between trials was .05 apparent foot-candles.

The conditioned stimulus consisted in an increase in brightness of the disc to 1.51 apparent foot-candles. The duration of the conditioned stimulus on each trial was 550 msec. Five hundred msec. following the onset of the CS, the unconditioned stimulus, a puff of air, was administered in the region of the external canthus of the right eye. The air puff was produced by the fall of an 80-mm. column of mercury, magnetically released, in a manometer. Intertrial intervals of 15, 20, and 25 sec., averaging 20 sec. and fixed according to a pre-arranged schedule, were employed.

The onset of the CS was controlled by the closing of a switch on an electronic timer (3). The latter, in turn, controlled the onset of the US at the appropriate time interval and the duration of the conditioned stimulus. An electromagnetic marker recorded the onset of the two stimuli on a Grass polygraph.

The closing of the eyelid was recorded by a combination of mechanical and electrical means. A modified Burlington Model 435 Power Level Meter was used in conjunction with a Thordarson type T 30W55 amplifier. The meter was mounted on an adjustable headband in such a position that the thread attached to the point of the meter could be fastened directly to a formed plastic extension fastened on the upper eyelid of the *S*. Thus any motion of the eyelid caused a voltage to be generated in the armature of the meter, which was amplified by the amplifier and ink-recorded on the polygraph paper as a deviation from a straight line by means of a Brush BL 902 Pen Motor. The latter was operated directly from the 500-ohm output tap of the amplifier output transformer.

Closure of the eyelid was recorded on the moving paper as a deviation from a horizontal line, the extent of this deviation being a function of both the amplitude and speed of the eyelid movement. A CR was recorded whenever the record showed a deflection of 1 mm. or more in the interval 200 to 500 msec. following the onset of the CS. Responses occurring less than 200 msec. after the onset of the CS were classified as original responses (alpha or beta) and were not included in the data.

Conditioning procedure.—Conditioning was carried out in two sessions, approximately 24 hr. apart. On day 1, each *S* first received three presentations of light alone. Subjects exhibiting more than one CR to the light were automatically excluded from the experimental groups. A single puff of air, unaccompanied by the light, was then administered and spontaneous blinking recorded for 40 sec. following onset of the puff. Any *S* who blinked (i.e., whose record showed deviation from a straight line) more than 20 per cent of the final 30 sec. of this period was also excluded from the experimental groups, although complete conditioning records were obtained for each of these *S*s.[6]

Immediately following the preliminary trials, all *S*s were given 20 paired presentations of the light and air puff. At the conclusion of trial 20, differential instructions were introduced as described above, half of each group receiving anxiety-producing instructions, half anxiety-relieving. Following administration of the instructions, conditioning trials 21–70 were given in the same fashion as trials 1–20.

In a second experimental session on the following day, 10 additional conditioning trials were given. After the final conditioning trial, half of each group was given extinction trials to a criterion of 10 successive response failures. The remaining half of each group was subjected to a special set of conditions that will not be discussed here as they are concerned with a problem outside the scope of the present experiment.

The same initial instructions prior to the conditioning trials were given to all *S*s. These were originally designed to acquaint the *S* with the general experimental situation and to produce a more or less neutral set so that responses would be neither inhibited nor facilitated. No additional instructions were given at the beginning of the second session. At the end of the first experimental session all *S*s were given a questionnaire in which their understanding of instructions and reactions to the experimental situation were ascertained.

Results

Effects of Differential Instructions on Development of the CR

Curves of acquisition of the CR based on the percentage of anticipatory responses occurring in successive

[6] Since it is impossible to distinguish between conditioned responses and spontaneous blinks occurring in the same time range of the CR, *S*s who show high blinking rates spuriously inflate conditioning data, especially in the earlier blocks of trials. For this reason, *S*s with a high blinking rate were eliminated from the experimental groups. Of the 4 *S*s exceeding the criterion, 3 were from the anxious group, so that this criterion did not favor the group for which the prediction of superior conditioning had been made.

blocks of 10 trials for the four subgroups are presented in Fig. 1. The two upper curves show the course of conditioning for the anxious subgroups (anxious plus and anxious minus). It will be noted that the two curves overlap, neither showing any consistent superiority. The same overlapping and lack of difference is also apparent in the lower pair of curves which represent the learning of the two non-anxious subgroups.

That the total amount of conditioning, the per cent of CR's in all 80 trials, did not differ for the plus and minus groups is apparent from Table I. The differences, it will be noted, are very small and without significance.

On the possibility that the effect of the instructions may have been only temporary, a further analysis was made of the magnitude of the increase in percentage of CR's made from the block of trials (11–20) preceding the instructions to the blocks (21–26 and 21–30) immediately following. Table II presents the means of increases. It will be seen that in every instance but one, the plus groups made a greater increase than the corresponding minus group. Furthermore, the differences were greater for the shorter 5-trial period than for the longer 10-trial period. These results suggest

TABLE I

MEAN PERCENTAGE OF CR'S EXHIBITED ON 80 CONDITIONING TRIALS

Group	Mean Percentage of Total CR's	σ_M
Anxious Plus	59.75	4.767
Anxious Minus	59.45	6.261
Non-anxious Plus	29.14	4.968
Non-anxious Minus	26.63	6.749

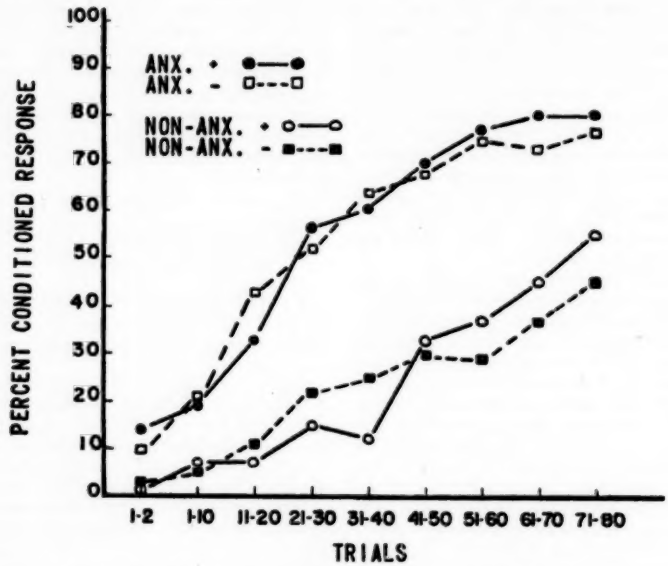

FIG. 1. Acquisition curves showing the percentage of CR's in successive blocks of 10 trials for the four experimental groups

that the instructions may have had a very brief differential effect. However, none of the differences was statistically significant, the largest t, that obtained for the difference between the anxious plus and anxious minus groups for trials 11–20 versus 21–25, was 1.61, significant at only the 20 per cent level of confidence.

While the instructions may have had a slight and very temporary effect on the conditioning, the data indicate that the hypothesis that there is no difference between subgroups cannot reasonably be rejected. Accordingly, the data of the two anxious and the two non-anxious subgroups have been combined so that only two groups of 30 subjects, an anxiety and a non-anxiety group, will be treated in further discussion of the results.

Effect of Anxiety and Non-anxiety on the Strength of the CR

The distributions of percentages of CR's for the anxious and non-anxious Ss occurring in trials 21–50, 51–80, and 1–80 are presented in Fig. 2, and the corresponding medians of the percentages in Table III. Although there is overlapping between the two groups in each of the three sets of conditioning scores, the anxious group is clearly superior in amount of conditioning. A non-parametric test, described by Mann and Whitney (6), was employed to test the hypothesis that there was no difference with respect to the distribution of scores for each of the three sets of CR measures. On the basis of this hypothesis the probability that the obtained differences

TABLE II

MEAN INCREASE IN PERCENTAGE OF CR'S MADE FROM BLOCKS OF TRIALS PRECEDING THE INSTRUCTIONS, TO THE BLOCKS IMMEDIATELY FOLLOWING

Group	Increase of CR's			
	Trials 11–20 vs. 21–26		Trials 11–20 vs. 21–30	
	Mean Per-Cent	σ_M	Mean Per-Cent	σ_M
Anxious Plus	20.3	7.2	17.7	5.2
Anxious Minus	4.7	7.5	12.7	6.4
Non-anxious Plus	13.7	4.3	10.7	5.8
Non-anxious Minus	5.7	5.4	12.0	6.0

TABLE III

MEDIAN PERCENTAGE OF CR'S GIVEN FOR THE SPECIFIED TRIAL BLOCKS BY THE ANXIOUS AND NON-ANXIOUS GROUPS

	Anxious	Non-anxious
Trials 21–50	69.0	13.3
Trials 51–80	81.7	41.7
Trials 1–80	64.7	22.6

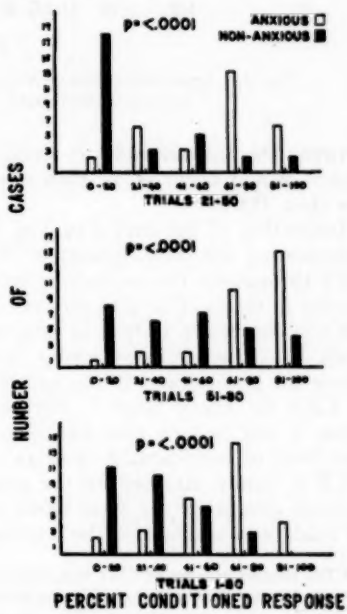

FIG. 2. Distributions showing the percentage of CR's given by the anxious and non-anxious groups in different trial blocks

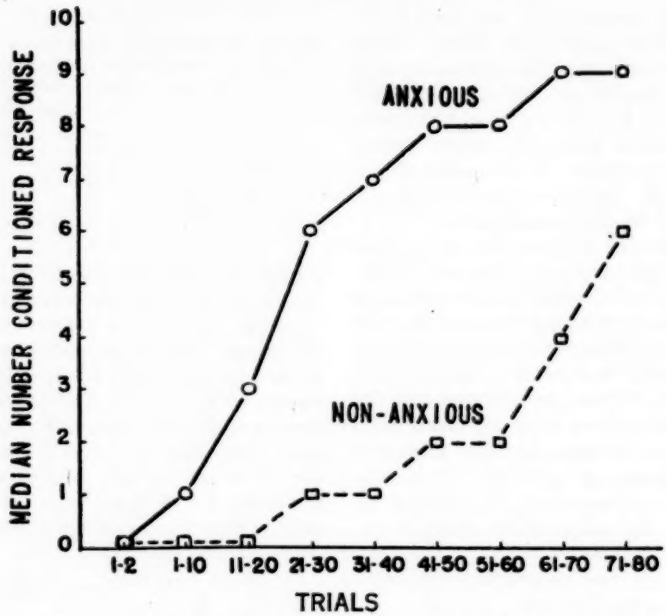

FIG. 3. Acquisition curves showing the median number of CR's for the anxious and non-anxious groups in successive blocks of 10 trials

between the anxious and non-anxious groups would occur is, in each case, less than .0001.

Inspection of the curves in Fig. 3, representing the development of the CR's throughout the course of conditioning in terms of median number of CR's in successive 10-trial blocks, reveals that the anxious group was above the non-anxious in the number of CR's for every block.[7] Furthermore, it will be seen that the 50 per cent level of conditioning (median of 5 CR's) barely attained by the non-anxious groups in the final block of 10 trials was reached in the anxious *Ss* as early as trials 21–30. The shape of the conditioning curves suggests that the anxious *Ss* had reached an asymptote or limit of conditioning by the end of the training trials, whereas the curve for the non-anxious group was still showing an increase.[8]

The data on resistance to extinction, obtained from 14 anxious and 14 non-anxious *Ss*, are presented in Table IV.[9] Although the anxious group is higher in both the mean number of responses and mean number of

[7] The median number of CR's was used because it does not distort the conditioning scores as does the mean percentage of CR's. In the early blocks of trials, the latter measure tends to be high, while on the last blocks, the mean per cent score tends to be distorted downward.

[8] In a subsequent experiment by the writer and K. W. Spence in which 100 conditioning trials were given, it was found that the asymptote of the non-anxious group was reached by 80 trials.

[9] As was stated previously, approximately half of the *Ss* in each group was given extinction trials, the remaining *Ss* being subjected to experimental conditions in connection with a problem outside the scope of the present experiment.

TABLE IV

MEAN NUMBER OF CR's AND MEAN NUMBER OF TRIALS TO THE EXTINCTION CRITERION OF TEN RESPONSE FAILURES

Group	No. of CR's to Extinction Criterion		No. of Trials to Extinction Criterion	
	Mean	σ_M	Mean	σ_M
Anxious	2.35	.49	15.43	1.45
Non-anxious	1.50	.41	12.35	.20

trials to the extinction criterion of 10 response failures, the difference between the means in neither case is significant. However, the *t* computed for the trial measure is between the 5 and 10 per cent level of confidence, while the *t* for the number of CR's is at the 20 per cent level. It is possible that the differences would be more significant with a greater number of *Ss*.

DISCUSSION

Anxiety Level in Relation to the Development of the Conditioned Response

The consistent superiority of the anxious group in all measures of conditioning and extinction strongly indicates that there is a marked difference in the rate with which the strength of the CR is developed under the two conditions of drive (anxiety) level. This might be interpreted to mean that anxious *Ss* have a more rapid conditioning rate, or, in Hull's terms, develop habit strength ($_sH_R$) at a faster rate. While this is a possibility, it should be noted that in Hull's theoretical formulation of the assumed relations between response strength, excitatory potential ($_sE_R$), habit and drive strength, $R = f(_sE_R) = f(H \times D)$, the slope of the rise of the $_sE_R$ value, and hence the response measure, is a direct function of *both H* and *D* values. Thus, it is theoretically possible for the habit growth curves for two groups of *Ss* to be identical and yet have both the $_sE_R$ and response curves increase at two quite different rates in the two groups because of different *D* values.

In the present experiment an attempt was made to manipulate the variable *D* by obtaining varying strengths of an independent response measure (anxiety) in two groups of *Ss*. That is, it was assumed that drive level (*D*) varies directly with differing degrees of anxiety, the latter being defined in terms of the number of positive verbal responses made to test items judged to be indicative of anxiety.

In terms of Hull's formulations, higher levels of *D* should lead to a more rapid growth of the $_sE_R$ curve and hence to a more rapid rise in the frequency curve of CR's. The results of the experiment are in agreement with these assumptions in that the frequency of response curve for the high drive (anxious) group was considerably higher than that for the low drive group.

It is also theoretically possible, however, to interpret the experimental results in terms of the second variable, $_sH_R$, i.e., the different performance curves for the two groups could be the result of more rapid learning (increase in *H*) in the anxious group, as well as higher drive level. It might be argued that the anxious group reacts more strongly to the UCS so that while the UCS is physically equal for the two groups, it is a more intense stimulus psychologically for the anxious *Ss*. If this were the case, then the cessation of the UCS would result in a greater reduction in *D* in the anxious group, and hence in greater increments of $_sH_R$ (ΔH), as the magnitude of the reward is postulated by Hull to be one of the variables deter-

mining the increment of ${}_{S}H_{R}$. The present experiment offers no conclusive evidence favoring one or the other of these alternative interpretations.

Clinical Concepts of Anxiety and Their Relation to Amount of Conditioning

In clinical usage, the concept of anxiety is employed in at least two very different ways: (1) as the term applied to a particular behavior syndrome, and (2) as a hypothetical construct that is assumed to determine certain types of overt behavioral adjustments.

In the first sense, the definition of anxiety seems to be fairly unambiguous: a group of widespread, directly observable overt reactions (e.g., restlessness, tenseness, excessive perspiration, etc.) are identified as "manifest anxiety" and considered as the definition of anxiety neurosis. Further, these symptoms are assumed to be accompanied or paralleled by internal emotional responses (primarily controlled by the autonomic nervous system). It is this definition of anxiety which was adopted in the present experiment, the test items being descriptions of the response syndrome clinically termed "anxiety." Thus, different numbers of positive responses to the test items were assumed to reflect different degrees of manifest anxiety and of the parallel internal responses as well. It will be recalled that the assumption made earlier was that Hull's intervening variable, drive (D) is some positive function of the intensity of this internal emotional response.

The theoretical construct of anxiety has reference to a hypothetical state or event occurring under the skin of the organism. The construct is introduced in connection with behavior disorders (e.g., hysteria, paranoia, compulsions) in which the overt symptoms are considered to be a defense against the hypothetical internal anxiety state. The occurrence of these response symptoms is assumed to reduce the anxiety at least partially and temporarily.

Thus, in the case of manifest anxiety, as the result of past experiences, the internal response and the overt anxiety behavior occur, the former presumably determining the drive level. In the second instance, as a result of previous experience, the hypothetical anxiety state is aroused and followed by the occurrence of defense reactions reducing the anxiety.

What relationship this second hypothetical anxiety construct has to Hull's drive is a question. It might be postulated that the functional properties of the internal anxiety state are similar to those of the internal responses occurring in manifest anxiety, so that different degrees of the hypothetical anxiety will be accompanied by different levels of drive. If this is the case, then the defense reactions can be considered to be a function of a high drive level. However, to the extent that the defense responses are effective in reducing drive, drive level will be low.

If these assumptions are correct, then the conditioning procedure provides a valuable technique for the investigation of this hypothetical anxiety state in the various behavior disorders. That is, the effectiveness of a particular defense syndrome in reducing the internal anxiety should be reflected in the strength of the conditioned responses exhibited by individuals with these symptoms, as compared with a group of normals. For example, the classic hysteric should

show an equal or lesser amount of conditioning than the normal, since the hysterical symptoms are postulated to be more or less completely and continuously effective in reducing anxiety. On the other hand, if the repetitive act can be prevented from occurring, individuals exhibiting a repetitive compulsion should be superior conditioners, since these responses are believed to be preceded by an increasingly higher amount of anxiety. Thus, by the conditioning technique, an indirect measure is provided so that speculations concerning the role of the hypothetical anxiety in the behavior disorders can be subjected to experimental test.[10]

Summary

The present experiment attempted to evaluate the hypothesis that the amount of conditioning exhibited in a defense conditioning situation is a direct function of the level of total effective drive.

Two groups of 30 *Ss* each were chosen on the basis of extreme scores made on a test of manifest anxiety, those with high scores being the anxious (high drive) group, and those with low scores being the non-anxious (low drive) group. Both groups were run in a conditioned eyelid situation. During the course of the conditioning trials, differential instructions, designed to raise or to lower anxiety level, were administered, half of each group receiving anxiety-producing, and half anxiety-relieving instructions.

The results indicate that the subgroups receiving differential instructions did not differ in the amount of conditioning in the subsequent course of the training trials, showing that the instructions had little or no effect. The data from the anxious and non-anxious groups show that the anxious group was consistently superior in amount of conditioning throughout the course of the conditioning trials, the difference between the two groups being highly significant statistically.

The data on resistance to extinction, obtained from 14 of the anxious and 14 of the non-anxious *Ss*, indicate that although the anxious group was higher in both measures of extinction, the difference between the two groups was in neither case significant.

The results are interpreted to mean that such sources of drive as those employed in the present experiment combine in some manner to produce a total effective drive state, and that this value is a determiner of the strength of the conditioned response.

(Manuscript received February 20, 1950)

[10] A study utilizing this technique is currently being carried out by the writer and K. W. Spence to test these hypotheses with several diagnostic groups.

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NEW GRADIENTS OF ERROR REINFORCEMENT IN MULTIPLE-CHOICE HUMAN LEARNING[1]

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Demonstration of the differential influence of reinforcement on responses not themselves directly reinforced would certainly seem to demand significant modifications in basic learning theory. However, from the earliest announcement by Thorndike (**9, 10**) of the spread of effect phenomenon, learning theorists have taken a somewhat dim view of its significance (e.g., **2, 13**). More recently direct experimental tests of certain of the criticisms raised have accumulated evidence purporting to show that the Thorndike gradient, although widely confirmed and on a solid empirical basis, is actually an artifact of such factors as isolation (**15**), number-guessing habits (**3, 4, 5, 7**), and probability bias (**8**).

The purpose of this paper is to present preliminary evidence of new gradients of error reinforcement which suggest a general spread of reinforcement process in a way that is essentially free of the major criticisms directed against the Thorndike type of gradient. A generalized reinforcement hypothesis is offered to account for these results, and more precise experimental tests of it are planned.

[1] The empirical parts of this report were presented in a paper read at the St. Louis meetings of the Midwestern Psychological Association, May, 1942.

[2] The experiments were performed at Washington University.

Procedure

Subjects

Subjects were upperclass college students, naive as to the purpose of the experiment. They were tested in three groups as follows:

Experiment A.—Fifteen *S*s were given 10 trials with a fixed and pre-arranged pattern whereby for certain regularly spaced stimulus words any number choice was right, and for all other words any choice was wrong. One reinforcement came early in the list and one late, with 12 errors in between. Although this relationship held in all cases, the exact position of the reinforcements was not the same for all *S*s. The purpose of this variation was to avoid having all of the *S*s receiving reinforcement simultaneously. Conversation with these *S*s following the experiment indicated, in accordance with the reports of other investigators (e.g., **14**) who used such a pre-arranged system, that the artificial nature of the situation had not been discovered.

Experiment B.—Eleven *S*s were given 20 trials in the usual multiple-choice learning situation with one number arbitrarily selected as "correct" for each word.

Experiment C.—Twenty-six *S*s were given 16 trials under the same conditions as in Experiment B.

Apparatus

Each *S* was provided with a specially constructed punch-board type learning box, record sheets with the stimulus words mimeographed along the left margin, and a needle stylus (dissection type) with a wooden hilt. The box was 8½ in. long, 5½ in. wide, and 3½ in. deep. It was made of a galvanized metal base with a three-piece punchboard masonite top. The record sheet was inserted by *S* between the upper two parts of the punch-board top. The 25 stimulus words were exposed one at a time by means of a sliding wooden rider. A cardboard guide extended from the rider to the right immediately below each row of 10 apertures. The numbers 1 through 10 were typed on it. Choice of any of

the 10 numbers for each stimulus word was made by the insertion of the stylus point into the appropriate aperture. Correct choices were indicated by the running of the stylus through the aperture to the hilt, a distance of 3 in. Incorrect choices were indicated by the stopping of the stylus by a metal key which was fitted directly under the middle board. In either case a permanent record was left of each response since the stylus invariably pierced the paper record sheet. At the end of each trial the record sheet was turned by *S* around inside the curved right side of the apparatus and thus directly inserted into the hollow interior of the box. No additional time interval was used between trials. This means of removing the record sheets was adopted as a precaution against possible review of choices.

Learning Materials

Each stimulus list was composed of 25 common, English five-letter, two-syllable adjectives. They were read off by *E* to the group at a regular rate of 1 every 3 sec.

Orthodox verbal learning instructions were used. The *S*s in each experiment were read verbatim instructions emphasizing that this was a learning experiment in which numbers were to be associated with words; that they were to guess any number from 1 to 10 at random for each word, since numbers had been arbitrarily assigned; and that their major task was to learn and remember as many of the corect numbers as possible.

Because of the imperative need for highly restrictive scoring conditions in the analysis of the data, and the consequent difficulty of obtaining representative numbers of cases for individual *S*s, tests of significance based upon samples of individual scores were not attempted. Data were pooled for the group as a whole, in order that major trends might be discovered.

Results

Gradients of Error Reinforcement Measured Between *S–R Connections*

The Thorndike gradient.—Figures 1 and 2 present the typical Thorndike gradient as it occurred in the present study. Figure 1 is based upon the data from Experiment A, in which the pre-arranged and fixed system of reinforcement was used. Figure 2 is based upon the data from Experiment B, in which the normal random system of reinforcement was used. The total numbers of errors upon which these frequency percentages have been based varied from slightly over 50, for the most peripheral positions, to almost 800, for the most central. The greater regularity of the gradient effect in Fig. 1, without a single reversal up to six positions preceding and six following a reinforced re-

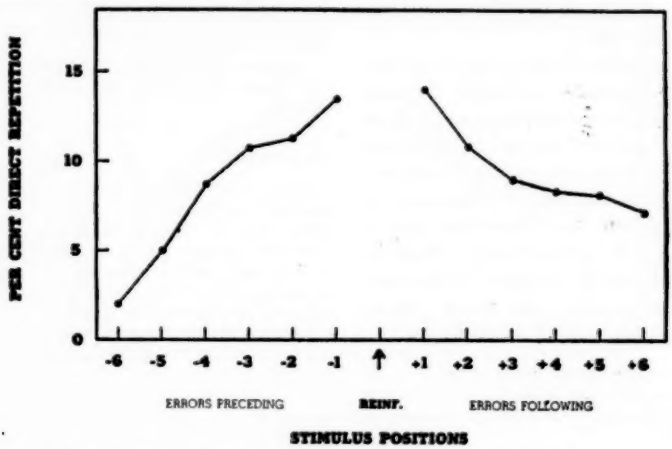

Fig. 1. Thorndike gradient under conditions of fixed reinforcement

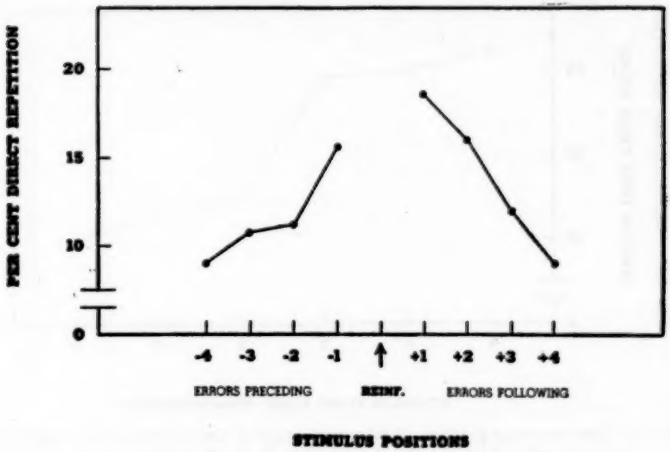

FIG. 2. Thorndike gradient under conditions of random reinforcement

sponse, may be tentatively attributed to the less complicated reinforcement system in Experiment A.

Although it is considered to be of some interest, from an empirical if not an explanatory point of view, that these gradients should show up so clearly and so extensively, it must also be pointed out that they are open to certain of the objections levelled against the typical Thorndike gradient. They are presented primarily to show that the present data, when scored in the orthodox manner, produce the typical Thorndike gradients.

The error-recovery gradient.—In the preparation of the orthodox Thorndike gradient the percentages of error repetition are based upon the relative frequencies of direct repetition of errors from one trial to the next. All such direct repetitions may be ignored, however, and measurement made instead of the relative frequencies of repetition of errors which were originally made two or more trials earlier. This type of repetition may be called "discontinuous," to distinguish it from the direct or continuous type. Relative frequencies of error repetition measured in this way indicate the extent to which *S*s tend to repeat numbers previously and incorrectly guessed but subsequently varied.

An error-recovery gradient of this kind is shown in Fig. 3, based upon a total of over eighteen hundred responses in Experiment A. In the preparation of this gradient data from comparable stimulus positions on each side of the reinforced response were pooled in order to increase the number of cases available for analysis. Such a sacrifice of precision, with regard to the question of bi-directionality, is justified in the present exploratory study since we are most concerned with finding major trends.

Owing to the fact that the pre-arranged and fixed reinforcement in Experiment A occurred in the same stimulus position on every trial, the error-recovery gradient of Fig. 3 is open to several interpretations. It is possible that the number-guessing habit and the probability-bias factors were both operating, although there was no way under the present experi-

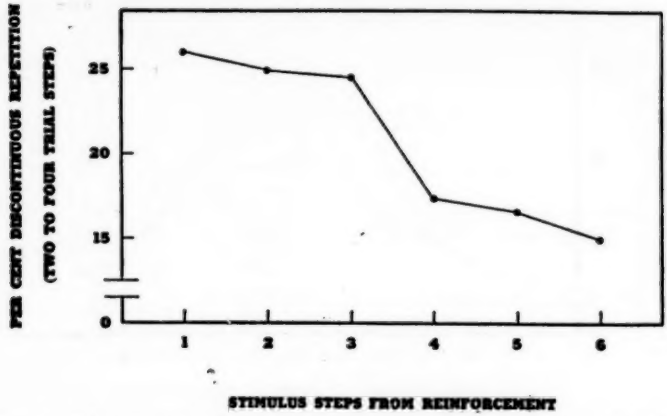

FIG. 3. Error-recovery gradient showing percentage of discontinuous error repetition as a function of distance in stimulus steps from a fixed reinforcement

mental conditions to test them. Two additional hypotheses may be considered. In the first place, the differential strengthening of errors may have been due to a proactive operation of the Thorndike phenomenon. Thus errors which are close to correct responses may be reinforced so that, although they do not immediately recur upon the succeeding trial, they are nevertheless more likely to recur at some time on future trials, and are then scored as discontinuous repetitions. By this explanation the error-recovery gradient, while offering additional support for the Thorndike type of gradient and indicating a somewhat wider range of its applicability, would nonetheless entail no radically new theoretical assumptions.

A second interpretation is that reinforcement on any given trial somehow acts to strengthen responses made as errors on *earlier* trials to nearby stimuli, increasing the probability of their recurrence on the next trial as their distance from the correct response in stimulus steps, is decreased. Such an interpretation would involve apparent "retroaction" of an even more extreme nature than that required in the Thorndike gradient, in which errors previously made on the *same* trial seem to be strengthened. By it, as will presently be shown, the Thorndike gradient may be reduced to a special case of a more general spread phenomenon.

The data of Experiment A cannot be regarded as crucial with respect to any of these hypotheses, and the data of Experiments B and C were subjected to further analysis. We computed the relative frequencies with which errors made on the first trial were repeated on the third, fourth, and fifth trials after having been replaced on the second trial. Stimulus-step positions were again combined, in this case in groups of two steps before and after reinforcement, in order to increase the number of data available for each category under the highly restrictive special scoring conditions.[3]

[3] These conditions were, briefly, as follows: (1) No repetition of the first-trial reinforcement was permitted in the key stimulus position within the critical trials scored. (2) Possible retroactive influences from second-, third-, or fourth-trial reinforcements were controlled by counting

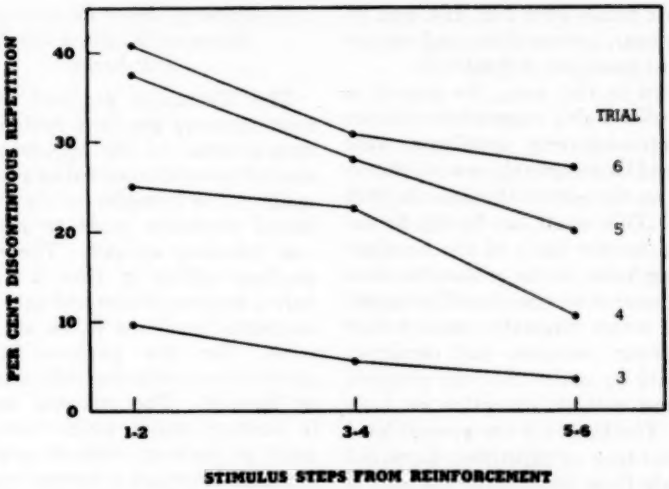

FIG. 4. Error-recovery gradients showing percentage of discontinuous error repetition as a function of distance in stimulus steps from a new reinforcement on the preceding trial

No evidence of a gradient was found in any of the three trials scored. The percentages of error repetition, for the three trials combined, were as follows: stimulus steps 1 and 2, 13.1 (14/107); stimulus steps 3 and 4, 19.2 (10/52); and stimulus steps 5 and 6, 13.9 (5/36).

This result, while tending to throw doubt upon the importance of the extension of the Thorndike type of intra-trial reinforcement, as an explanation of the error-recovery gradient of Fig. 3, obviously offers no positive evidence for a more general *inter-trial* retroactive influence. In order to obtain a more direct test of this hypothesis, we scored the data of Experiment C for error-recovery gradients around completely *new* reinforced responses on the second through the fifth trials. Error positions before and after correct responses were again combined in steps of two, as in the last analysis and for similar reasons. Discontinuous repetitions of errors on the third trial, following a new second-trial reinforcement, were of course based only upon responses originally made on the first trial. Discontinuous repetitions of errors on the fourth trial, following a new third-trial reinforcement, were based upon errors made on the first and second trials. Discontinuous repetitions of errors on the fourth and fifth trials were similarly based upon errors made on the first three and the first four trials, respectively. Only those error sequences were scored which were entirely free of reinforcements. Percentages of error recovery were again based upon the total number of possible discontinuous repetitions, with direct repetitions excluded from the computations. For all four trials analyzed, the combined

only those errors that were at least three stimulus steps removed from any such correct responses. (3) Direct error repetitions, such as from the second to the third trial, were not computed in the total used to determine the discontinuity repetition percentage. (4) Only the first repetition of the error was counted.

response totals were 273, 154, and 98 for the near, intermediate, and remote stimulus positions, respectively.

Scored in this way, the curves of Fig. 4 offer highly suggestive evidence that error-recovery gradients were produced by completely new reinforcements on the second through the fifth trials. This result can hardly be explained on the basis of the number-guessing habit or the probability-bias factor, since it was produced by repetition of errors originally made before the correct response had occurred. It should be noted that the gradient appeared without exception on each trial. The fact that the general level of percentage of repetition increased regularly from one trial to the next is of course explained by the increased number of responses available for repeating on later trials.

One more or less incidental result of the foregoing analysis was sufficiently striking to justify a brief mention. At every stage of learning there was apparently a consistently greater tendency for errors to be *directly* repeated when they were near reinforced responses which were themselves *discontinuously* repeated, as compared with new correct responses or fixated ones (total error repetition of 19.5 per cent, compared with 12.3 per cent and 13.4 per cent). The direct repetition percentages for the three types of correct responses themselves were as might be expected, with the lowest percentage of repetition found for new responses and the highest for fixated responses. This apparent generalized disinhibiting effect of such recovered reinforced responses may be seen as a potentially important function, should this result be substantiated by subsequent research.

Gradients of Error Reinforcement Measured Within *a Single S–R Series*

The Thorndike gradient and the error-recovery gradient both involve measurement of the apparent influence of the reinforcement of a response made to one stimulus on the nonreinforced responses made to preceding and following stimuli. The present gradient differs in that it involves only a single stimulus and the various responses made to it on successive trials. For the purposes of this analysis inter-stimulus influences may be ignored. The essential question is whether errors which have been made on previous trials to any given stimulus to which a correct response is subsequently made, are then strengthened according to their distance, in terms of *trial units*, from the reinforced response; and, conversely, whether errors which follow a single reinforcement closely—on the succeeding trial, for example—tend to be strengthened more than those which follow more remotely.

We may first consider, in Experiments B and C, those S–R series in which different errors were made on the first three trials and were followed on the fourth trial by a successful response. The relative frequencies with which these three early errors were repeated on the five trials immediately following the reinforcement, were measured. The control situation consisted of one in which three consecutive and different errors were also made on the first three trials but were followed by a fourth—and different—error. No subsequent reinforcement was permitted within the next four trials in either case.

The two curves on the left in Fig. 5 show the relative error repetition fre-

quencies, based on response totals of 167 and 855 in the reinforcement and control situations, respectively. It may be seen that whereas the strengthening of the first two errors was practically identical in both types of situation, there was a considerable difference with regard to the two types of third-trial errors. The error which immediately preceded the reinforcement was repeated more than twice as frequently on subsequent trials as the third-trial error in the control situation.

A similar result also appeared in the situations in which four consecutive and different errors were followed by a fifth-trial new error or a correct response. The two curves are shown at the right in Fig. 5 and are based on response totals of 77 in the reinforcement and 480 in the control situation. The differential strengthening of the errors preceding reinforcement may be seen here even more clearly, owing to the extremely low frequency of recurrence of the earliest errors in the reinforcement series. It should be noted that there was no overlapping between the two sets of data graphed in Fig. 5.

The question may now be asked as to whether this differential influence of reinforcement on errors was a bidirectional one. In other words, does reinforcement also tend differentially to influence the probability of recurrence of those errors which are made on subsequent trials? An attempt was made to answer this question by utilizing those situations in which a first-trial reinforcement was followed by several successive and different errors. Reinforcement situations of this kind were less frequent than those in which the error series preceded the reinforced response, and only those situations with three successive errors yielded enough data for analysis. In both reinforcement and control situations the four trial positions immediately following the fourth-trial error

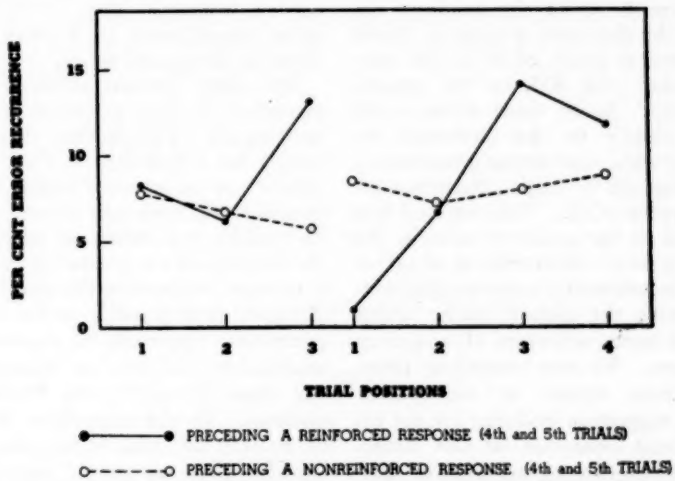

FIG. 5. Relative frequencies of recurrence of errors as a function of their original occurrence on the trials preceding either a reinforced or a nonreinforced response to the same stimulus

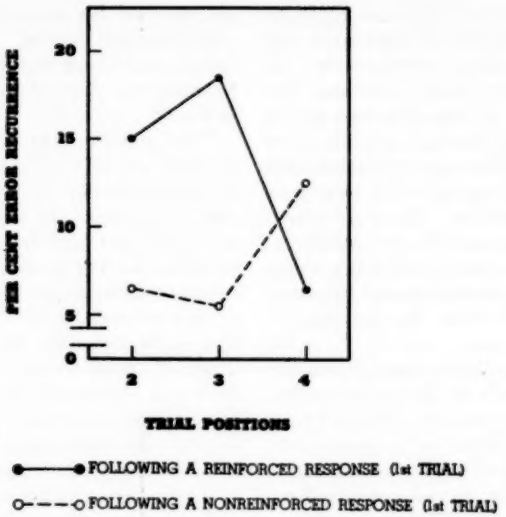

FIG. 6. Relative frequencies of recurrence of errors as a function of their original occurrence on the trials following either a reinforced or a nonreinforced response to the same stimulus

position were kept free of reinforced responses, and the error frequencies were based upon trials 5 through 9.

Figure 6 shows the gradient obtained by this type of analysis, based on response totals of 60 in the reinforcement and 855 in the control situation. Again those errors made most closely to the reinforced responses were most strongly reinforced, as measured by their recurrence on subsequent trials. This resulted in a reversal of the gradient found in the other type of reinforcement situation and a consequently more marked contrast with the control curve, which showed some indication of a recency influence. We may tentatively interpret these results as constituting strong suggestive evidence for the bidirectional character of the differential strengthening influence of reinforcement upon nonreinforced responses made to the same stimulus.

A further indication of the influence of the single reinforced response in the series may be seen in the fact that errors made preceding or following a correct response were consistently more strengthened, *as a group*, than those in the control series.

One fairly obvious alternative explanation of these gradients may be anticipated. This is that they may simply be a function of *S*'s "uncertainty" as to exactly which of his previous responses was the one which he vaguely remembers as successful. On the basis of the present data, there is no way to eliminate this possibility. However, it is possible to use an experimental approach to control the uncertainty variable, as Muenzinger and Dove (6) did for the Thorndike gradient. In the meantime, it may be pointed out that it is quite conceivable that *S*s should experience varying degrees of "uncertainty"—whether or not overtly expressed—even when their responses are actu-

ally determined in a strictly "mechanical" manner.

A Generalization of Reinforcement Hypothesis

It is difficult to see how any of the major criticisms directed against the Thorndike gradient can be applied to the gradients presented in Figs. 4, 5, and 6. The factors of isolation (15), guessing habits (3, 4, 5, 7), and probability bias (8) seem to be of highly questionable relevance. Other objections (cf. 1, p. 44 ff.) to the earlier Thorndike gradients are likewise inapplicable. In the measurement of the present gradients, stage of learning, degree of practice, and number of stimulus steps were all controlled. Empirically determined baselines of chance expectancy were not involved since we were concerned only with relative frequencies within a single series of errors. Moreover, the "uncertainty" variable, while not yet eliminated as a possible factor in the gradients measured within a single series of responses to the same stimulus, can scarcely be used to explain the inter-stimulus error-recovery gradients based upon discontinuous repetitions around a completely new reinforcement.

Certain theoretical implications have been drawn from the results of this analysis. A tentative hypothesis has been developed in an effort to bring all of the empirically determined gradient effects into one general explanatory system and to provide a preliminary theoretical framework for future experimental tests. This generalized hypothesis will be briefly outlined.

Figure 7 shows in simple diagrammatic form the three kinds of gradients which have been thus far reported. The Thorndike gradient is represented by solid-line arrows, the inter-stimulus error-recovery gradient by broken-line arrows (with bi-directionality assumed), and the intra-stimulus gradient by dotted-line arrows. Differential strengthening influence as a function of distance, in stimulus or trial steps, is shown by differential thickness of the arrows.

It becomes apparent from consideration of Fig. 7 that the various re-

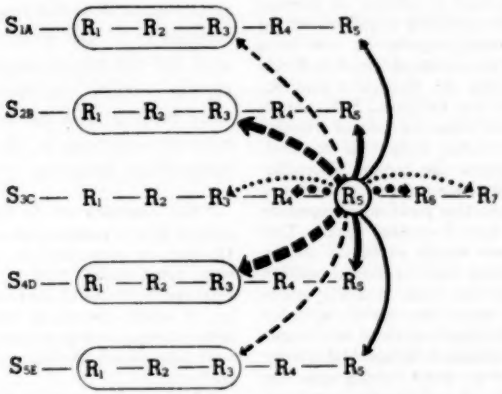

Fig. 7. Simplified diagrammatic representation of three kinds of gradients of error reinforcement. The single reinforced response is circled.

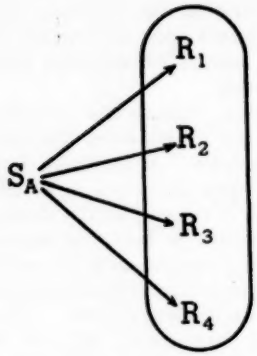

FIG. 8. Functional organization of responses made to the same stimulus

sponses may be grouped into a variety of functional organizations. Three such functional relationships of responses are diagrammatically shown in Figs. 8 and 9.[4] Figure 8 represents the hypothetical cluster of responses which are made to the same *stimulus*. Figure 9 represents the organization of responses into clusters as a function of simple temporal variables as a result of their common occurrence in a particular *ordinal position* of presentation (solid line, horizontal organization) and on a particular *trial* (broken line, vertical organization).[5] Clusters of responses may thus acquire functional relations by reason of their mutual connections within the same stimulus dimensions.

It is our hypothesis that the reinforcement of any given response has a measurable strengthening influence on those other responses which bear the *closest functional relation* to the reinforced response. The fact that any given response has concomitant functional relations along a variety of dimensions suggests a solution to the problem of response interaction and the resulting gradient effects. Reinforcement of a response may be assumed differentially to influence the habit strength of certain responses as a function of their proximity within any of its own systems, and of responses in other systems as a function of their closeness of relationship to the reinforced system. The tendency more frequently to repeat errors the more closely they were previously made in temporal relation to a single reinforced response to the same stimulus, or in the same ordinal presentation position, is thus the result of the direct influence of the reinforced response; and the tendency more frequently to repeat errors discontinuously when they belong to a more closely related response system is the result of the interaction between systems.[6]

[4] The complex nature of the total stimulus situation, and the need to consider all relevant aspects even in the relatively simplified setting of the typical learning experiment, have been pointed up by certain results obtained by Zirkle (14). He found that the Thorndike gradient, scored in the usual way for formal S–R connections, did not appear when the order of stimulus presentation was varied from trial to trial. However, he obtained the typical Thorndike gradient when responses were scored in terms of their ordinal presentation positions irrespective of the particular stimuli evoking them. This result may be most simply explained on the reasonable assumption that the ordinal position factor tends to develop more naturally stable response systems than the verbal stimulus factor, under the distinctly artificial word-number association conditions of the usual laboratory experiment. It has no direct bearing upon the present hypothesis, in which no particular stimulus aspect is assumed to be essential or of special intrinsic importance.

[5] The tendency of *Ss* to make numerical guesses in non-random sequences (3, 4, 5, 7, 12, 13) may be interpreted as another example of such functionally related response systems. Presumably the result of pre-experimental learning, it would operate to strengthen the trial-oriented response sequence and contribute to the more pronounced development of the Thorndike gradient.

[6] Additional support for this hypothesis may be found in Thorndike's (11) study showing that "irrelevant" neutral responses (letters) were

From a strictly psychological point of view we do not need to be directly concerned with the particular neurophysiological mechanisms by means of which these functional response relations are established and the various interaction effects mediated. This is also true of the problem of the apparent retroactive and proactive effects of reinforcement. Nevertheless, it is considered worth while to make what appears to be an entirely reasonable suggestion as a corollary to the behavioral analysis. If we assume that all responses are represented by—based upon—certain enduring neural modifications, then we may further assume that it is these neural correlates which, at the time of reinforcement, are further and differentially modified. The differential modification—and thus the response-system interaction—may be assumed to be a function of the degree to which the correlates possess some common neurophysiological characteristics resulting from their common occurrence in a particular ordinal presentation position, on a given trial, etc.[7]

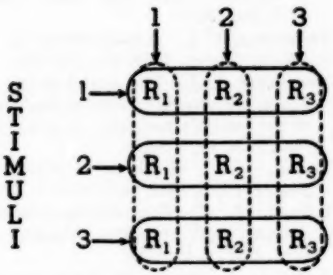

FIG. 9. Functional organization of responses made in the same ordinal position of presentation (solid line) or on the same trial (broken line)

One additional assumption is required for the problem of the apparent proactive effect (as produced, for example, by a first-trial reinforcement on subsequent nonreinforced responses to the same stimulus). This is that the neural modifications which occur as a result of reinforcement somehow operate to change the neural correlate in a way that *persists*—neurophysiologically and thus behaviorally—and so may continue to influence other functionally related responses as they are made on subsequent trials.

SUMMARY

The present report is concerned with the apparent influence which reinforcement of one response has upon the probability of recurrence of other responses not themselves directly reinforced. Detailed analysis of the multiple-choice learning records of 52 human *Ss* revealed not only the clear-cut operation of the Thorndike spread of effect type of gradient, but also two new error-reinforcement gradients which do not seem explicable on the grounds of the various criticisms levelled against the Thorndike gradient. These were: (1) an error-recovery gradient according to which errors made several trials previously tended to be repeated more frequently, following the occurrence of even a com-

more frequently repeated when appended to reinforced responses (numbers).

[7] The fact that recovered reinforced responses (that is, those discontinuously repeated) were more likely to be associated with a consistently higher level of error repetition on the subsequent trial may be indicative of a more intensive neural interaction effect accompanying the reactivation of reinforced responses. On the basis of the present hypothesis, we would expect to find an at least equally marked advantage of discontinuous error repetition around such reactivated responses. Although not tested in the present analysis, this prediction could very well be tested in later work.

pletely new reinforced response, as a function of their closeness in stimulus presentation steps to the reinforcement; and (2) an intra-stimulus error-recovery gradient according to which errors tended to recur more frequently in later trials as a function of their closeness, in terms of trial units, to a single reinforced response made to the same stimulus.

A tentative hypothesis was developed to explain these gradients of error reinforcement. It was suggested that they are most effectively explained on the basis of the assumption that responses are organized into a variety of functional systems which are susceptible to interaction effects resulting from reinforcement.

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THE EFFECT OF REINFORCEMENT ON THE ALTERNATION OF GUESSES

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The problem of predicting human and animal behavior in a repetitious two-choice situation has intrigued investigators for a number of years. The behavior of rats at a maze choice point or of human beings making guesses or judgments offers a simple, objectively measurable criterion for the evaluation of predictions made from different empirical or theoretical bases. The use of such a criterion to test learning theory is best illustrated by the long series of latent learning experiments using a simple one-choice T-maze as the measuring yardstick. Predictions have been made as to rat behavior at such a choice point from several conflicting learning theories and the empirical confirmation or refutation of the predictions used to evaluate the adequacy of the rival theories.

A situation at the human level analogous to the animal multiple T-maze is a series of guesses or judgments of which side of a coin will appear when tossed. That such guessing behavior is not random has been shown by Skinner (6) and Goodfellow (1, 2). Solomon (7) attempted to test the concept of reactive inhibition using guesses as the dependent variable by varying the time interval between guesses and the effort required to make the guesses. Using the behavior theory of Hull (4) he predicted that increased effort in making the guesses, or decreased time between guesses, would increase the amount of the alternation of response in a two-alternative problem. Using time intervals of from 5 sec. to 8 min. and variations in guessing effort in both group and individual testing situations, showed no evidence of affecting the amount of nonrepetitive behavior on the part of the *S*s. Within the time and effort limits used by Solomon, reactive inhibition does not seem to be a useful concept in human guessing behavior.

Another set of predictions about the effects of reinforcement upon the alternation of guesses is the subject of this experiment. The postulates used by Hull (4) would predict that rewarding or reinforcing a response such as a guess would have the effect of increasing the probability of a repetition of that response on the next elicitation and that the effect of the reinforcement would be greater the larger the number of responses that are rewarded.

PROCEDURE

The *S*s used were 100 college students in two introductory psychology classes as the control group and 108 students in two general psychology classes as the experimental group. The students in the control group were asked by their instructor[1] to guess a priori what sides would come up on the three tosses of an ordinary coin about to be tossed by their instructor. The students' guesses were recorded on cards and collected before the coin was actually tossed by the instructor and the results of the tossing were announced to the class. This group will be referred to as the "No Reward" group. The experimental group was divided into four sections and each section tested independently. The students in each section were asked by their instructor[2] to record their guesses as to which side would appear on the first toss of a coin; the instructor then tossed the coin and informed the

[1] The author wishes to express his appreciation to Dr. George W. Albee for providing the control group subjects.

[2] The author.

section of the results. This result was also recorded by each student on the card containing his guess. The students then recorded their guesses as to the second toss, the instructor tossed the coin and again informed the students of the result, and the result was recorded by each student on the card containing his guess. This process was repeated for the third toss, and the cards containing the recorded guesses and obtained results were collected from the students. Regardless of which side actually appeared on each toss of the coin the instructor announced predetermined sequences of heads and tails to the sections, the sequences differing for each of the four sections. Sequences used were THH, HHH, HTT, and TTT. Predetermined instead of the actual sequences were used to insure a more equal spread of correct and incorrect guesses among the sections. On later questioning by the instructor none of the students reported being aware that a predetermined order was used. Since the students in this group had the opportunity of having some of their guesses rewarded as correct and others not rewarded, this group will be called the "Reward" group.

Results and Discussion

If we equate the reward of making a correct guess in the above situation to the reinforcement of the behavioral response of making the guess, then certain predictions can be made as to the differences between the Reward and No Reward groups. Since reinforcement of a response according to Hull (4) has the effect of increasing the probability of a repetition of the same response on a subsequent elicitation, we could predict that fewer alternations should appear in the Reward group compared with the No Reward group. Table I compares both groups as to the number of alternations of response made and shows that significantly fewer alternations were made by the Reward group. Here reinforcement has had the effect predicted; it has significantly decreased the amount of alternation. A successful guessing of a particular coin side facilitates the repetition of that same side on the next guess. However, an unsuccessful guess does not have the opposite effect of facilitating alternation, for with an approximately equal number of successful and unsuccessful guesses in the Reward group such an effect would balance off the reinforcement restriction of alternation and the Reward group would have the same number of alternations as the No Reward group. This is in line with the current view of the effect of non-reinforcement, which does not posit an equal and opposite effect for non-reinforcement or for punishment (3).

TABLE I

Number of Alternations in the Reward and No Reward Groups

Number of Alternations	Reward Group	No Reward Group
0	50	14
1	48	73
2	10	13
Total	108	100

$\chi^2 = 25.52$ $P < .01$

TABLE II

Relationship between Number of Reinforcements and Number of Alternations in the Reward Group

Number of Alternations	Number of Reinforcements		
	0	1	2
0	26	19	5
1	6	31	11
2	2	6	2
Total	34	56	18

$\chi^2 = 18.41^*$ $P < .01$

* Obtained by combining the middle and bottom rows to eliminate small expected values.

As to the other prediction, the effect of increasing numbers of reinforcements upon the number of alternations of guesses is shown in Table II. The variables of number of reinforcements and number of alternations are shown by the chi-square test to be

significantly related as predicted. However, while Table I shows the effect of reinforcement is to decrease variability, Table II indicates that the greater the number of reinforcements the greater will be the variability of response. Evidently the effects of reinforcement are cumulative as far as influencing the alternation of guesses.

An important factor that has yet to be investigated in the alternation of guesses is the concepts of probability held by the subjects. To some a 50–50 chance of occurrence or nonoccurrence implies that the events will tend to alternate. Also, the occurrence of a head on one toss of a coin is generally thought to increase the probability of a tail's appearing on a subsequent toss. Such higher mental processes may disturb the operation of such constructs as reactive inhibition and reinforcement in human alternation problems and should be investigated as independent variables as important as or more important than Hullian constructs.

In general, this study has suggested that the effect of reinforcement of human guesses is to decrease the number of alternations of response. This effect is what would be predicted from Hull's learning theory. However, the effect of the reinforcement is a function of the number of reinforcements and acts to increase behavioral variability as a cumulative effect of the reinforcements. It is suggested that individual concepts of probability, as mentioned by Solomon (7), and individual "guessing habits," as investigated by Jenkins and Cunningham (5), are more important in the prediction of human guessing behavior than are concepts such as reactive inhibition and reinforcement and that these variables should be investigated along with the more theoretical systematic constructs.

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THE PERCEPTION OF THE VERTICAL: V. ADJUSTMENT TO THE POSTURAL VERTICAL AS A FUNCTION OF THE MAGNITUDE OF POSTURAL TILT AND DURATION OF EXPOSURE [1]

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Previous studies from this laboratory have examined in an exploratory manner the effect of varying magnitude of postural tilt and varying durations of exposure to tilt upon adjustment to the postural vertical. Mann and Passey (3) found evidence for a differential effect of amount of initial tilt upon adjustment to the postural. The amounts of body tilt employed were 10°, 45° and 90°. The differences in average error and constant error in the direction of initial body tilt were not as great for angles of tilt between 45° and 90° as for angles between 10° and 45°. The constant error in the direction of initial tilt and the average error increase with the amount of initial tilt up to about 45°. The data approximate a negatively accelerated increasing function of amount of tilt. Since only three points were obtained, the true function is not at this time known.

Passey and Guedry (6) found that exposure to tilt for periods of 60 sec. produced greater errors in adjustment to the vertical than when the adjustments were made immediately following tilt. They termed this phenomenon "adaptation to tilt." Mann and Passey confirmed this finding, noting a shift of constant error in the direction of initial tilt when *Ss* were exposed to tilt for periods of 60 sec. Mann, Passey, and Ambler (4), using a constant amount of body tilt and exposure times of 0, 15, 30, and 45 sec., found that greater shifts in constant error in the direction of initial tilt accompanied greater exposure times as the time of exposure approached 45 sec.

The present study is concerned with the joint problem of the effect of the amount of postural tilt and the duration of exposure upon adjustment to the postural vertical in the absence of a visual frame of reference. The following null hypotheses are tested: (1) For all amounts of initial postural tilt, adjustments to the gravitational vertical will be made with (*a*) equal variability, (*b*) equal precision, and (*c*) there will be no shift of constant error in the direction of initial tilt; (2) for all exposure times, adjustments to the gravitational vertical following exposure to initial postural tilt will be made with (*a*) equal variability, (*b*) equal precision, and (*c*) there will be no shift of constant error in the direction of initial tilt.

[1] This report is part of a series of investigations conducted jointly with the School of Aviation Medicine and Research under Contract N7onr-434, Task Order I, with the Office of Naval Research in cooperation with the Bureau of Medicine and Surgery and the Tulane University of Louisiana; project designation number NR140-455 of the Medical Sciences Division, Office of Naval Research; Project NM 001 037 of the Research Division, Bureau of Medicine and Surgery; Task Order Director: Cecil W. Mann.

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Apparatus and Procedure

The apparatus used in the present experiment was the Navy orientation box designed by Dr. H. A. Witkin and described elsewhere by Passey (5).

The procedure used was to bring *S* into the experimental room and place him in the experimental chair. He was then given the following instructions: "This is an experiment to see how well you can adjust yourself to an upright sitting position when you are placed in a tilted position. I will tilt you to some inclined position and when I instruct you to do so you are to return the chair as nearly as you can to the position in which you are now. When you are satisfied with your position inform me by saying 'level.' I will then return you to the upright position and inform you that you are now 'level.' Following this you will be placed in another inclined position. You can move the chair by pressing these buttons [demonstrate]." During the course of the experiment *S* was blindfolded and the experimental room was darkened to eliminate visual cues.

Eight durations of exposure of 0, 5, 15, 25, 35, 45, 55, and 65 sec. were used. Six amounts of tilt—5°, 15°, 25°, 35°, 45° and 55°—were used. All combinations of tilt and exposure time were used, giving 48 combinations in all. For each combination five adjustments were made from the right and five from the left in the lateral plane. Each *S* made 480 judgments distributed in a random fashion throughout 20 experimental sessions of approximately 45 min. duration each. In each pair of sessions the entire 48 positions were covered.

Three male psychologists served as *S*s. The *S*s were employed in research in this field, and their familiarity with this and similar investigations was recognized.

Results

In order to investigate hypotheses 1*a* and 2*a* the technique suggested by Bartlett (1) was employed. Checks of the data for "crude average error" and constant error were made. For the data of average error a *P* of approximately .50 for tilt and a *P* between .50 and .25 for time of exposure was found. For the data of constant error *P*'s of approximately .75 for tilt and between .05 and .10 for time of exposure were found. On the basis of this finding the assumption of homogeneity of variance is justified in making further analyses employing the technique of analysis of variance. With increasing initial body tilt and increasing time of exposure the data show no significant change in variability. We therefore accept hypotheses 1*a* and 2*a*.

TABLE I

Mean Average Error (Degrees) of Adjustment to Gravitational Vertical from Various Positions of Body Tilt

Time of Exposure in Seconds	Amount of Body Tilt in Degrees						
	5	15	25	35	45	55	Mean
0	1.1	1.4	1.0	1.2	1.5	1.4	1.3
5	1.1	1.3	1.6	1.3	1.3	1.4	1.3
15	1.3	1.6	1.6	1.5	2.1	1.9	1.7
25	1.6	1.6	2.0	1.5	2.0	2.1	1.8
35	1.5	1.4	1.9	1.8	1.6	2.0	1.7
45	1.5	1.4	2.1	2.1	1.9	2.0	1.8
55	1.4	2.0	2.0	2.5	2.3	1.6	2.0
65	1.2	1.8	2.0	1.8	1.8	2.1	1.8
Mean	1.3	1.6	1.8	1.7	1.8	1.8	

The data for average error, which is taken as a measure of the precision of adjustment, are presented in Table I. Each entry in this table is the mean for 30 adjustments, 10 for each *S*, 5 from the indicated position in each quadrant. Since the data for each quadrant revealed no difference with respect to quadrant, they have been

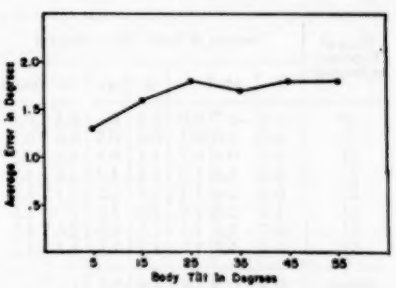

Fig. 1. Average error of adjustment to gravitational vertical for various amounts of initial body tilt

TABLE II

ANALYSES OF VARIANCE FOR DATA OF AVERAGE ERROR

Source	Sums of Squares	*d.f.*	Variance Estimate
Amount of Tilt			
Columns (Tilt)	0.58	5	0.12
Rows (*Ss*)	3.20	2	1.60
Interaction	0.20	10	0.02
Total	3.98	17	
Time of Exposure			
Colums (Time)	1.35	7	0.19
Rows (*Ss*)	4.81	2	2.41
Interaction	0.63	14	0.05
Total	6.79	23	

combined. The data for average error as a function of tilt are presented in Fig. 1. Each of the plotted points is the mean of 240 adjustments, 80 for each *S*. Analyses of trends in the data were made employing the method suggested by Lindquist (2). The analysis of the trend in the data of average error as a function of the amount of initial tilt is presented in Table II. The *F* obtained was 6.0 and the $P < .01$ (*d.f.* 5 and 10). We reject the hypothesis that the plotted data have a slope of zero. With increasing amounts of initial tilt there is an increasing average error of adjustment; hence we reject hypothesis 1*b*.

The mean average error for adjustment as a function of the duration of exposure is plotted in Fig. 2. Each point is the mean of 180 adjustments, 60 for each *S*. The analysis for trend shown in Table II gave an *F* of 3.80 and a *P* between .05 and .02 (*d.f.* 7 and 14). We reject hypothesis 2*b*, which held that the data would have a slope of zero. With increasing duration of exposure to initial tilt there is an increasing average error of adjustment.

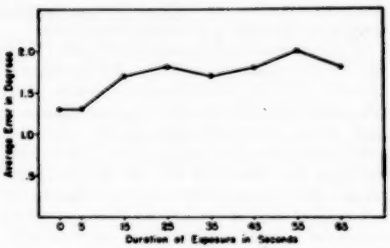

FIG. 2. Average error of adjustment to gravitational vertical for various durations of exposure to body tilt

TABLE III

MEAN CONSTANT ERROR (DEGREES) IN DIRECTION OF INITIAL TILT FOR ADJUSTMENTS TO THE GRAVITATION VERTICAL FOR VARYING AMOUNTS OF TILT AND VARIOUS DURATIONS OF EXPOSURE *

Time of Exposure in Seconds	Amount of Body Tilt in Degrees						
	5	15	25	35	45	55	Mean
0	−0.2	−0.5	0.0	0.8	0.6	0.4	0.2
5	0.3	1.0	0.1	0.6	0.5	0.6	0.5
15	−0.1	0.6	0.7	1.1	0.9	1.2	0.7
25	0.4	0.8	1.3	1.4	1.3	1.6	1.1
35	0.3	0.6	1.1	1.8	1.2	1.3	1.1
45	1.2	0.6	1.4	2.0	1.9	1.9	1.5
55	0.7	1.1	1.7	2.1	1.9	1.6	1.5
65	0.1	1.5	1.7	1.1	1.5	1.3	1.2
Mean	0.3	0.7	1.0	1.4	1.2	1.2	

* Negative values indicate constant error in opposite quadrant from initial tilt.

Table III contains the data for constant error. Since the data for each quadrant showed no differences, they were combined. Each tabular entry is the mean of 30 adjustments. Figure 3 presents the data for mean constant error in the direction of initial tilt for various amounts of initial tilt. Each of the plotted points is the mean of 240 adjustments, 80 for each *S*. Results of the test for trend are shown in Table IV. The *F* obtained was 11.50, and the *P* was $<.001$ (*d.f.* 5 and 10). The data for constant error

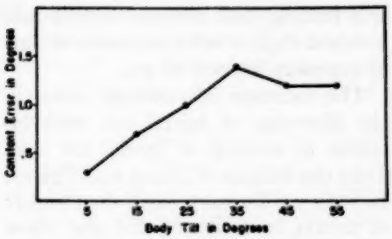

FIG. 3. Mean constant error in direction of initial tilt for adjustments to the gravitational vertical for various amounts of initial body tilt

show an increase in constant error in the direction of initial tilt for increasing amounts of initial tilt. The slope of this trend is greater than zero. We reject hypothesis 1*c*.

Figure 4 shows a plot of the mean constant error in the direction of initial tilt for increasing durations of exposure. Each point represents the mean of 180 determinations, 60 for each *S*. Results of an examination of the data for trend, as shown in Table IV, gave an *F* of 17.38, with a *P* of <.001 (*d.f.* 7 and 14). With increasing duration of exposure to tilt there is increasing constant error in the direction of initial tilt; this trend has a slope greater than zero. On the basis of this finding we reject hypothesis 2*c*.

TABLE IV

ANALYSES OF VARIANCE FOR DATA OF CONSTANT ERROR

Source	Sums of Squares	*d.f.*	Variance Estimate
Amount of Tilt			
Columns (Tilt)	2.31	5	0.46
Rows (*Ss*)	8.71	2	4.36
Interaction	0.40	10	0.04
Total	11.42	17	
Time of Exposure			
Columns (Time)	210.44	7	30.06
Rows (*Ss*)	32.53	2	16.27
Interaction	24.16	14	1.73
Total	267.13	23	

DISCUSSION

Examining both average and constant error of adjustment for homogeneity with increasing amounts of initial tilt and durations of exposure, we found that there was no increase in the variability, save that which might be attributed to chance. Passey and Guedry reported earlier that they found a significant increase in variability for delayed as opposed to immediate readjustments. Mann and Passey and Mann, Passey, and Ambler, using a lateral tilt chair, found no increase in variability with increase in exposure time and increase in

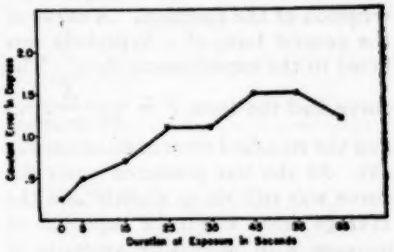

FIG. 4. Mean constant error in direction of initial tilt for adjustment to the gravitational vertical for various durations of exposure to body tilt

amount of initial tilt. The present experiment was performed in a lateral tilt device. It is possible that the increase in variability noted by Passey and Guedry was a function of the apparatus used, which allowed greater freedom of movement and may have affected the judgments of *Ss* in this manner.

In the absence of a visual frame of reference it has been shown that *Ss* can adjust to the postural vertical with great precision and accuracy when adjustments are made immediately following initial body tilt. Delay in a tilted position for a period of 15 sec. was necessary to produce a

change in precision of adjustment, as revealed in the index of crude average error. Accuracy of adjustment is shown to be affected by a delay as short as 5 sec. when accuracy is indicated by the index of constant error.

The trend toward increasing average error of adjustment with increasing amounts of initial tilt confirms the earlier work of Mann and Passey. They used only three amounts of tilt and found that the average error at their maximum amount of tilt, 90°, was not significantly different from the average error for tilts of 45°. The present finding extends their work and allows a more complete description of the function. A curve of the general form of a hyperbola was fitted to the experimental data. The curve had the form $Y = \frac{X}{.94 + .54X}$, and the standard error of estimate was .06. At the last predicted point the curve was still rising slightly and the average error might be expected to increase with increasing amounts of initial tilt beyond 55°.

Increasing average error accompanying increasing duration of exposure confirms the work of Passey and Guedry when immediate versus non-delay readjustment is considered and further confirms the work of Mann, Ambler, and Passey with respect to increase of average error with increase in exposure time. Our present results allow for description of this function. A curve of the general form of a hyperbola was fitted to the data. The curve fitted had the form $Y = \frac{X}{.95 + .53X}$. The standard error of estimate was .09. This curve tended to rise slowly with an increase in time when extrapolated beyond the limits of time employed in this study. It would be expected on the basis of this finding that average error would increase slightly with increases in time of exposure beyond 65 sec.

The increase in constant error in the direction of initial tilt with increase in amount of initial tilt confirms the finding of Mann and Passey. In their preliminary work the number of points investigated did not allow for a description of the function involved. A curve fitted to the data of the present study had the general form of a hyperbola described by the equation $Y = \frac{X}{13.6 + .5X}$. This curve tends to increase when extrapolated beyond the limits of the present experiment. The standard error of estimate was .14. Mann and Passey found that there was no significant increase in constant error between 45° and 90°. The value predicted by our equation would fall within the standard error of estimate of the obtained value for 55° and could thus be a chance fluctuation representing no real increase. The present findings show a smaller average error than did the data of Mann and Passey, and this is possibly an artifact of the equipment. The tilting device used in the present study was capable of more accurate subject control since a magnetic brake served to stop the movement of the chair when the control botton was released.

The increase in constant error in the direction of initial tilt with increase in the duration of exposure to tilt is a confirmation of the finding of Mann, Passey, and Ambler. The irregularity which they found in the left quadrant is not present in our data. A curve fitted to these data is that of a hyperbola having the form $Y = \frac{X}{6.34 + .64X}$. The standard error of estimate for this prediction is .18.

This curve does not provide for the decrease in the value of constant error for 65 sec., although this value falls within the standard error of estimate.

The curves which have been fitted are intended to describe the trend of the data obtained. These curves serve as a point of departure for the development of a systematic theory of perception of the postural vertical. They represent a first attempt at systematic quantification of relevant variables in the perception of the postural vertical. For values greater than those used experimentally, and on the basis of our exploratory work with values of the experimental variables in excess of those presently employed, extensions of the curves would seem reasonable. There remains the task of testing with greater values of the experimental variables before the functions can be legitimately extended.

Summary

1. Three *S*s were subjected to tilts of 5, 15, 25, 35, 45, and 55 degrees in the lateral plane, and were maintained in these positions of lateral tilt for periods of 0, 5, 15, 25, 35, 45, 55, and 65 sec. prior to being allowed to return themselves to the gravitational vertical. Each *S* was given 10 adjustments from each position of tilt and time of exposure, making 480 adjustments for each *S*. Half of the adjustments of *S* were made from the left upper lateral quadrant and half from the right upper lateral quadrant. The adjustments were made during 20 experimental sessions for each *S*.

2. With increasing duration of exposure to tilt there is an increasing average error of adjustment and a shift of constant error of adjustment in the direction of initial tilt.

3. With increasing amount of initial tilt there is an increasing average error of adjustment and a shift of constant error in the direction of initial tilt.

4. With increase in the duration of exposure to tilt and with increasing amounts of initial tilt there is no significant change in variability of either average or constant error.

5. Results are related to previous work in this area, and curves are fitted to the empirical data. These curves are proposed as theoretical functions.

(Manuscript received January 30, 1950)

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POST-ROTATIONAL PERCEPTION OF APPARENT BODILY ROTATION [1]

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The term "oculogyral illusion" has been introduced to designate certain visual apparent motion phenomena which occur during and after rotation (**4, 5**). This illusion is divided into the first, second, and third effects during rotation and the first, second, and third effects after rotation. Although oculogyral illusion, as originally defined (**4, 5**), is specific to those situations in which the apparent motion of a visual target in an otherwise dark room is reported, the present report will utilize the terms first and second post-rotational effects in connection with post-rotational apparent *rotation* where visual stimulation is absent.

Investigations of post-rotational effects may involve the use of two main types of measurement: (1) subjective reports indicating (*a*) the cessation of feelings of apparent motion in the absence of visual stimuli and (*b*) the cessation of apparent motion of visual stimuli. When such reports are made, duration is yielded as a measure of the post-rotational aftereffects. (2) Objective measurements of post-rotational effects. These have consisted chiefly of the application of different methods of recording nystagmic eye movements, and these records may yield time, amplitude, and frequency measures.

There is some question as to whether these variants of post-rotational effects originate from the same source. For example, some of the sensations of movement following rotation may be attributable to the visual component, i.e., to the tracking of images over the retina during nystagmic eye movements (**6**), but since sensations of movement occur with blind *Ss* and also with blindfolded *Ss* in a dark room, it would seem that all apparent motion after rotation cannot be causally related to this visual component.

In this connection Dodge (**2**) has presented evidence that there is no absolute relation between the cessation of nystagmus and cessation of the awareness of apparent rotation in the dark. The question of the relationship between the variants—nystagmus and apparent rotational phenomena—is one which has been given considerable attention since the time of Purkinje. In 1820, Purkinje (**8**) held that there is always a strict correspondence between the duration, direction, and intensity of vestibular nystagmus and the duration, direction, and intensity of the illusory rotation of the environment produced by the eye movements comprising the nystagmus. This view was contested by Bárány (**1**), who failed to find a strict correspondence between the above variants but found that the

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subjective accompaniments of nystagmus tend to habituate with repeated rotations, while the nystagmus itself shown no significant change. Opposed to this view is the position of Holsopple (7), who found that in some cases nystagmus may be greatly reduced in duration by means of repeated rotation without the duration of the post-rotational illusion of bodily turning appearing to be in any way affected.

The lack of agreement between these investigators as to the correspondence between the experiential phenomena and the nystagmus may be explained to some extent on the basis of inadequate measurement of the nystagmus as well as the variability in subjective reporting. Even assuming perfect correspondence between the duration of nystagmic eye movements and the duration of the visual illusion, any assumption concerning complete causal relationship between these two variants would be questionable in view of the results which have been obtained with blindfolded *Ss*. The questionable nature of this assumption is prefaced by the possibility that these variants are concomitant effects of still another factor.

The question in point is one which revolves about the controversy as to how much of the post-rotational effects may be ascribed to the visual component and how much may be attributed to a postural component. To avoid the questionable correlations of nystagmus and postural apparent motion, the present report will deal with two behavioral variants, *viz.*, apparent motion of a faint target line and apparent postural motion in the dark, and will employ two sets of experimental conditions.

If we assume that the rotational illusions are a result of either, or both, visual and postural variants, the perception of illusory rotation will be made on the basis of one of the three possibilities. If the perception is wholly dependent upon the visual component, then there should be no perception of illusory rotation in the dark. This we know is not the case. If the perception is wholly dependent upon the postural component, then the durations of the awareness of apparent rotation, with and without a faint visual stimulus, should be the same. A third possibility is that both may be operative. In this investigation it is proposed to use a second visual stimulus equated subjectively for brightness and in all respects identical with the first except that it be flickering light.

Illusory movement which is purely visual according to our definition must be due to the tracking of images across the retinae. By the use of a flickering light below c.f.f., different points of the retinae will be stimulated during nystagmic eye movements. When the retinal points stimulated are far enough separated to remain discrete in terms of retinal spread effects, a stimulus situation, with the one target, is produced which stimulates Phi stimulation. Under this condition, gross nystagmic movements will produce a Phi-like perception; when the amplitude of the nystagmic eye movements is reduced to a magnitude such that experientially the same retinal point is stimulated, the Phi-like perception will cease. At this point the contribution of the purely visual (retinal tracking of images) has ceased.

Apparatus

The principal item of apparatus was a Link Trainer so modified that it could be rotated in the horizontal plane up to 26 rpm and could be controlled from an adjoining room. In the cockpit was an iron stanchion supporting a biteboard which served to keep *S*'s head fixed over

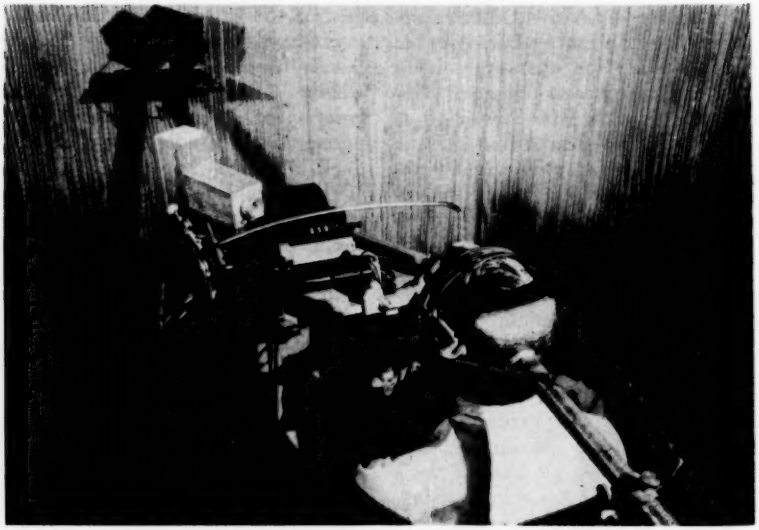

FIG. 1. Modified Link Trainer used as rotating device in the estimation of duration of oculogyral phenomena

the center of rotation and tilted slightly forward. The trainer occupied the center of a light-proof, nearly cylindrical room.

The air valves of the trainer were set to achieve a rotation of 20 rpm in a clockwise direction. The time for positive acceleration up to 20 rpm was about 15 sec., while that for negative acceleration (20 rpm to zero) was about 0.5 sec.

The targets employed for subject fixation were situated in the horizontal plane on a level with the *S*'s eyes. The distance from *S*'s eyes to the target was 41.5 in. Two 0.5-in. vertical target lines, separated by 1.5 in. and approximately 1 mm. in width, were used. One target line was activated by constant direct current (CDC), and the second by intermittent direct current (IDC). The target lines were illuminated by ¼-w. neon bulbs, and their intensities were independently controlled. The rate of flicker for the IDC target was adjustable between frequencies of 3–30 cycles.

The *S* indicated cessation of apparent rotation by pressing a key which caused a light to flash in the control room. A standard electric timer enabled *E* to measure the duration of the illusions.

PROCEDURE

This experiment involved the use of three experimental conditions.

Condition A.—The *S* was rotated for 60 sec. with controls set to produce 20 rpm. This yielded approximately 44.5 sec. of rotation at 20 rpm, since 15.5 sec. were taken up by the acceleration and deceleration periods. The *S* was in complete darkness throughout condition A trials.

Condition B.—This situation was the same as for condition A except that the CDC target was to be observed throughout each experimental period.

Condition C.—This situation was the same as for conditions A and B with the exception that the IDC target was to be observed throughout each experimental period.

The *S*s were three male psychologists who had had previous experience in reporting the post-rotational apparent motion phenomena. The experiment was divided into two sections: In the first section each *S* was exposed to conditions ABABAB; in the second section each *S* was exposed to conditions CBCBCB, in that order during each session. For each *S* there were two sections, consisting of four sessions each, one in the morning and one in the afternoon for two successive days. For each *S* section 1 was followed by section 2 such that there were eight experimental sessions in four successive days. Within each session, time intervals between conditions for any one *S* were 5 min.

The *S*s were instructed to report the end of

TABLE I

MEAN VALUES OF DURATIONS OF FIRST POST-ROTATIONAL EFFECT AND ONSET OF SECOND POST-ROTATIONAL EFFECT UNDER CONDITIONS A AND B

Ss	Cessation of First Effect				Onset of Second Effect			
	Cond. A	Cond. B	*t*	*P*	Cond. A	Cond. B	*t*	*P*
JN	18.75	24.04	5.27	<.001	23.54	27.00	5.19	<.001
FG	19.91	21.63	3.15	<.01	24.17	22.67	−2.46	<.05
JR	24.71	23.54	−1.23	>.10	29.46	28.50	−0.84	>.10

the first post-rotational effect and the beginning of the second. An additional report was required in the case of condition C to denote the cessation of the Phi-like movements during the first post-rotational effect.

RESULTS

The results obtained for section one are represented in Table I. Inspection of Table I shows that while the times under conditions A and B were of the same order, the duration of the first post-rotational effect was significantly greater for two *Ss*, JN and FG, under condition B than under condition A. However, when the beginning of the second effect is taken as the basis of comparison for conditions A and B, it will be noticed that the relationship, B > A, does not hold for two *Ss*, FG and JR. The minus *t* values in Table I indicate the instances in which the relationship, $B > A$, does not hold. Although two of the three negative *t* values indicate chance differences, the third, in the case of FG, may be termed of borderline significance.

All three *Ss* reported that the target light (condition B) was blurred immediately after rotation and that the apparent motion was jerky, particularly during the beginning of the first post-rotational effect. This report of jerkiness, however, was obtained only in the presence of the target light (condition B); the *S*'s reports of the apparent rotation in the dark (condition A) were always of smooth movement. In Table II "Phi" designates the mean duration of the Phi-like movements during condition C. Prior to this series *Ss* were instructed that they were to press the response key, if Phi movements occurred, on the cessation of these Phi movements. Subjective reports on these movements were required after each rotation period. This yielded 12 reports on Phi by each *S* in condition C, or a total of 36 reports by all three *Ss*. There was only one case in 36 where no Phi movements were observed. With this one exception, every report indicated that there was Phi move-

TABLE II

MEAN DURATION OF PHENOMENA REPORTED DURING CONDITIONS B AND C FOR EACH SUBJECT

Ss	Cessation of First Effect				Onset of Second Effect				Duration of Phi
	Cond. B	Cond. C	*t*	*P*	Cond. B	Cond. C	*t*	*P*	
JN	22.79	23.88	1.5	>.10	24.17	25.38	1.4	>.10	16.25
FG	20.79	19.96	−1.11	>.20	22.13	22.38	0.28	>.70	7.00
JR	22.12	23.04	1.78	>.10	26.38	26.58	0.27	>.70	9.33

ment both to the right and to the left while at the same time there was over-all apparent motion to the left. Most of these reports indicated that good Phi movement had occurred in both directions.

For all three *S*s the duration of the Phi movements was in every case much shorter than the duration of the first post-rotational effect. The variability of the distribution of scores represented by the means given in Table II was, in every case, small enough that the means may be considered satisfactory representatives of their respective distributions.

The differences between conditions C and B may reasonably be attributed to chance in the case of each *S*, and beyond question of doubt the duration of the Phi-like movements (condition C) was less than the duration of the first post-rotational effect under condition B.

Discussion

The results cited above, as may be seen, tend to stress the importance of the contribution of the postural component to the first oculogyral effect. The term postural component is defined, admittedly by elimination only, as "some factor, or factors, other than vision." The postural component may, in addition to vestibular data, include many other sensory data. Dodge (**3**, p. 109) suggests ". . . kinesthetic perception, muscle strains, articular sensations, dermal sensations, as well as in consciousness of eye-movement . . ." as possible derivations for the perception of rotation.

The results obtained under condition A preclude the possibility that the perception of illusory rotation is wholly dependent upon the visual component, since illusory rotation was perceived in the dark.

When the results of all three *S*s are considered, it is to be noted that in three of the comparisons the mean duration of B was greater than that of A, while the converse was true in the other three comparisons. Since the inter-condition report variability for each *S* was found to be small, the reversals are interpreted as differences in *S* criteria of reporting the post-rotational effects. If this be the case, then the *t* values which indicate true differences must be held in question, and it can only be said that the duration values obtained are approximately of the same order. In other words, the duration of post-rotational effects in the dark is about the same as when a target light is observed.

Without excluding the possibility that both the visual and postural components may be operative to some extent, the alternative still exists that the perception of illusory rotation is wholly dependent upon the postural component. It is possible that, for the most part, the visual apparent motion phenomena associated with rotation may be attributed to an assumption made by the observers that, since the observer feels that he is rotating, the visual objects which remain in the visual field are assumed to be rotating because they are maintaining their position with respect to the observer.

Although this explanation is plausible, it does not account for the apparent displacement or the blurred appearance of the CDC light immediately following rotation. It is possible that tracking of images over the retina may be causally related only to these phenomena, and that the assumption of the postural effects is necessary for the over-all smooth apparent motion associated with rotation.

To investigate this possibility, a third experimental condition was

introduced (condition C). A single line of light adjusted just below c.f.f. was used as a visual stimulus. Observation of this target yielded not only the visual post-rotational apparent motion phenomena but, in addition, discrete Phi-like movements both to the right and to the left which lasted for only a portion of the first effect after rotation. Since eye movements seem the plausible explanation of the Phi-like movements in both directions, it seems unlikely that eye movements can also be the explanation of the over-all unidirectional smooth movement which occurs continually while the Phi effect is in progress and continues for some time after the Phi effect has subsided.

Explanation of Phi effects involves both eye movements and the intermittent stimulation afforded by the on-off phases of the light. During movement of the eyes, separate areas of the retina would be stimulated intermittently, with intervening areas not stimulated during the off-phase, which yields a situation very similar to Phi stimulation.

This explanation is supported by another deduction from rotational and post-rotational observations of *Ss* stimulated by light flashing at a rate above critical flicker frequency. Under these conditions the separate areas of the retina stimulated during the on-phase of the light would be closer together, and more areas would be stimulated in one sweep of the eye. Hence, following the line of reasoning used above, it would be expected that the *Ss* might report a "multi-line" (picket-fence) effect. This was found to be the case.

With respect to the first post-rotational effect, it appears that: (1) nystagmic eye movements contribute the *jerky* or *blurred* appearance which is commonly reported when a constant faint light source is used as a visual stimulus (condition B); (2) nystagmic eye movements in conjunction with the on and off phases of a flickering light simulate *Phi stimulation* and hence contribute Phi-like movements which manifest themselves only when a flickering light is used as a visual stimulus (condition C); (3) the postural component, i.e., some factor or factors other than retinal tracking, contributes the perception of apparent bodily rotation. Because this postural factor is undoubtedly also operative when visual stimulation is present, it is tentatively proposed that it contributes the smooth unidirectional apparent rotation movement, or drift, which follows the rapid, jerky visual response characteristic of the first phase of the oculogyral illusion. For the time being it seems appropriate to designate the postural component of the post-rotational phenomenon the "postural negative aftereffect."

Summary

This investigation was designed to determine the relative contributions of the visual and postural factors to the post-rotational effects of the oculogyral phenomenon. Comparisons were made of the post-rotational effects produced under conditions of (*a*) no visual stimulus, (*b*) continuous visual stimulus, and (*c*) flickering visual stimulus.

Three sophisticated *Ss* were used in the investigation. The equipment consisted of a Link Trainer modified to rotate at 20 rpm. Reports by the *Ss* of the cessation of post-rotational apparent movement under all conditions yielded subjective measures of the duration of the first effect of the oculogyral phenomenon.

1. The duration of the first effect under conditions A, no visual stimulus, and B, continuous visual stimulus, were of the same order.

2. A Phi phenomenon was experienced by observers at the commencement of the first effect. It was of variable duration for each observer, but in each case was of lesser duration than the total visual first effect.

It is concluded that the perceptual nature of the first effect of the oculogyral illusion is a result of two components: (*a*) a visual component which produces the rapid Phi phenomenon, probably a corollary of nystagmic eye movements, and (*b*) a postural component which contributes the smooth unidirectional apparent motion characteristic of the first effect.

It is proposed to designate the postural component the "postural negative aftereffect."

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THE NEGATIVE EFFECT OF PREVIOUS EXPERIENCE ON PRODUCTIVE THINKING

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The part which is played by past experience in human problem-solving behavior has long been a subject for experiment and discussion. Investigations viewing the evidence from different theoretical vantage points have arrived at diverse conclusions, which in some instances identify problem solving with trial-and-error learning (**3**), in other cases (**1, 8**) consider past experience in general as providing the raw materials out of which a problem-solving response may be fabricated, and on occasion some investigators have even neglected to consider the question of past experience as essential for a problem-solving theory (**9**). One of the reasons for the diversity of roles which have been accorded to past experience is that problem solving is by no means a unitary process. Although in all problem solving a solution is arrived at, the processes of behavior whereby the solution is achieved are of several different kinds. Maier (**8**) has served to clarify this issue by sharpening the often belabored distinction between *reproductive* and *productive thinking*. His discussion was developed in terms of the part which past experience may play in each type of performance. Reproductive thinking, Maier believes, is characterized by the solution of problems by means of the existence of stimulus equivalences in the novel (or problem) situation and in the previously mastered situation. Thus, for him, reproductive thinking and transfer of training are to be considered closely similar if not identical phenomena. *Productive thinking*, however, is not merely the process of arriving at a solution through the direct application of previous learning. In productive thinking past experience is repatterned and restructured to meet current demands, and is thus the counterpart of reasoning as Maier has defined that term (**6**). In the present study we are concerned with the relation of past experience to the productive thinking process, and not with reproductive thinking.

Probably the studies which have contributed most directly to an understanding of the manner in which the background of past experiences influences the nature of human productive thinking are those of Maier (**6, 7**) and Duncker (**2**). Maier, in his examination of the relation between stimulus equivalence and reasoning (**8**), identified several ways in which past experience may affect problem-solving activities. Problem solving may be facilitated by equivalences which exist in the immediate problem situation and in past experience. Further, as he has shown elsewhere (**6**), and as Birch (**1**) has shown for the chimpanzee, the background of past learning represents an essential repertoire of behavior which must be available for restructuring when new situational demands develop. On the other hand, productive thinking is impossible if the individual is chained to the past. The past experience may become a hindrance and an obstacle which blocks productive thinking and reduces behavior to stereotyped and fruitless essays.

It is primarily with this negative effect which may be exercised by past experience that Duncker has dealt in

his problem-solving experiments (**2**). In a series of situations designed to study what he terms "functional-fixedness," Duncker tried to determine the manner in which the previous utilization of an object for a dissimilar function in the *same problem context* affected its availability in subsequent problem solving, and found that such specific experience made the objects previously utilized in this manner significantly less available as instruments when the problem presented for solution was changed. Two weaknesses in experimental design limit the generality of the inferences which may be drawn from Duncker's results. In the first place, by using the same objective situation for both his "pre-utilization" experience and for his new problem-solving task, he makes it impossible to determine whether the difficulty in using a previously utilized object for the solution of a new problem derives from the limitation of the functional properties of this object by the prior experience, from the establishment of false problem-solving directions, from the development of attitudes of completion ("over and done with") on the part of the *S* which effectively remove the already-used object from the field of activity, or from any of a variety of other effects. Secondly, in selecting the different tools which would be available to the *S*s in their problem-solving activities, Duncker made no attempt to equate the instruments for different degrees of objective adequacy as tools in solving the problem. Obviously, if the objects in the "pre-utilization" group are objectively less adequate as tools then are the non–pre-utilized materials, the scales are weighted in favor of fewer solutions for the "pre-utilization" group. In not a few instances Duncker's problem situations may be criticized on these grounds, and the question arises as to whether his results derive as much from the pre-experimental object selection as from the effects of pre-utilization of the materials by the subjects.

To remove these impediments to interpretation of this aspect of the effects of previous experience on problem solving, it is necessary to study the problem under conditions in which the background of prior specific experience is obtained by the *S*s in a situation remote from the crucial problem-solving task, and to contrast as problem-solving tools objects whose adequacy as instruments is objectively equal. The design of the present study stems from these considerations.

Subjects and Procedure

Twenty-five students at the City College, New York, were used as *S*s in this experiment. These *S*s were divided into three groups, a control group and two experimental groups. The control group had 6 *S*s, and the experimental groups contained 10 and 9 *S*s, respectively.

As the crucial problem-solving task in this experiment, all *S*s were required to solve the two-cord problem used extensively by Maier (**7**) in his studies of "direction" in problem solving. In this problem the *S* is required to tie together the free ends of two cords which are suspended from the ceiling to the floor of a corridor. The distance between the two cords is such that the *S* cannot reach one cord if the other is held. In our arrangement the problem could be solved only if the *S* would tie a weight to the end of one of the strings and thus convert it into a pendulum which could be set swinging and then be caught on its upswing while the stationary cord was held. The two cords could then be tied together and the problem solved. In our situation only two objects could be utilized as weights. The first of these objects was an electrical switch and the second, an electrical relay. The conditions of pretest training involved the acquisition of differential prior experience with these objects by our *S*s. The pretest training was conducted as follows:

Group *S* contained 9 *S*s who were given the pretest task of completing an electrical circuit on a "bread-board" by using a *switch*, which had

to be installed if the circuit were to be completed and controllable.

Group *R* consisted of 10 *S*s who received pretest training in the completion of an identical circuit by the use of a *relay*, which is essentially a switch.

Group *C*, the control group, consisted of 6 engineering students with a wide variety of electrical experience. These *S*s were given no pretraining. The *S*s in groups *R* and *S* had had little or no experience with electrical wiring.

Shortly after having completed the pretesting tasks, the *S*s were presented with the two-cord problem and asked to solve it by using the objects lying before them on a table. Only two objects were present, a *switch* and a *relay*, each identical with the ones used in the pretraining period.

Since the two-cord problem is very difficult to solve without the presentation of "direction"-producing hints, such hints were presented by *E* 9 min. after the presentation of the problem. The hints consisted in brushing against the string or strings and "accidentally" setting them swinging. Solutions were always achieved within 3 min. after the presentation of hints. All *S*s were individually tested. Upon completing the two-cord problem, the *S*s were asked why they had chosen either the switch or the relay as the pendulum weight.

Results

The results reported will deal primarily with the nature of the choice of objects made by the *S*s in the critical task situation. These data for all groups are shown in Table I. The control group chose equally between the switch and the relay as pendulum weights which might be utilized for the solution of the two-cord problem. These data indicate that for individuals with prior experience which is not heavily weighted in favor of either the switch or the relay, no significant difference exists between the objects in terms of their utility as tools in solving the two-cord problem.

TABLE I

Frequency of Choice of Objects in Problem Solution

Group	*N*	No. Using Relay	No. Using Switch
Control (*C*)	6	3	3
Exper. (*R*)	10	0	10
Exper. (*S*)	9	7	2

The behavior of the *S*s who had received specific pre-utilization experience with either the switch or the relay differed in a striking manner from the behavior of the *S*s who had not received such experience. Those who had initially been trained to complete an electical circuit with a relay never utilized this object as the pendulum weight for the solution of the two-cord problem. In every instance the *S*s chose the switch, an object not previously manipulated, as the object which was to be converted into a pendulum bob in the solution of the two-cord problem. On the other hand, the *S*s who had initially been trained to use a switch for the completion of an electrical circuit preponderantly chose the relay as the pendulum weight in solving the two-cord problem.

If the results on solving the two-cord problem for both the switch and relay pre-utilization groups are combined, it is found that 17 of the 19 *S*s used that object with which they had had no pre-experimental training as the problem-solving tool. There are less than five chances in one hundred that such results could have occurred as the result of chance fluctuations in responding on the part of the *S*s. It may, therefore, be inferred that the nature of the previous specific experiences of the *S*s were influential in determining their problem-solving choices.

The replies which the *S*s made to the question, "Why did you use the switch (or relay) as the pendulum weight?" further indicate that the pre-utilization experiences exercised a decisive effect upon their problem-solving efforts. Those *S*s who used

the switch as the pendulum weight in the two-cord problem offered varying reasons for its superiority over the relay as a pendulum bob. They claimed that it was easier to attach, more compact, etc. The *S*s who tended to use the relay as the pendulum bob in solving the two-cord problem proffered equally "good" reasons for their selection. The relay, they claimed, was easier to attach, heavier, etc. In both groups of *S*s individuals became somewhat defensive when queried as to the reasons for their choices, and typically replied by prefacing their answers with the remark, "Anyone can see that this one is better as a pendulum weight." A number of *S*s even went so far as to say, "any *fool* can see that this one is better." Since these remarks are directed with equal vehemence at either the switch or at the relay, it is clear that the *S*s were not advancing objective reasons for their choices, but were, rather, revealing the effects which their prior specific experience was having on their perceptions.

Discussion

Although the present study was designed primarily to explore a neglected aspect of problem-solving behavior, it has some significance for problem-solving theory and provides clarifications for several important questions. In the first place, the results reveal that the question of the role played by past experience in productive thinking cannot receive a uniform answer until the nature of the past experience is clearly understood. Even though this study indicates that prior experience of a specific kind with a potential problem-solving tool effectively prevents this instrument from being used in problem solution, there is little doubt on the basis of other studies (**1, 4**) that a different kind of experience may enhance the value of an object as a tool in problem solving. Therefore, what appears to be important for problem solving is not that an individual's performance is dependent upon past experience per se, but rather that *different kinds* of experience are differentially effective in influencing the content of problem-solving behavior. Our results therefore are in accord with those of Katona (**5**), who found that *how* and *what* an individual learned and not simply *whether* he learned determined the amount of positive transfer effect that occurred in subsequent learning.

Perhaps the most interesting phase of our results concerns the manner in which the individual's previous experience influenced his perceptions. The pre-utilization experience apparently changed the perceived properties of the object previously used in a different context to such a degree that its problem-solving characteristic could not be readily seen. This change in perception was probably based on the manner in which the previous experience had emphasized the instrument as an *electrical object* and so made for extreme difficulty in perceiving it in terms of its general characteristic of *mass*, which is essential for pendulum construction. The kind of previous experience presented therefore functioned to limit the number of the properties of the object that could be perceived by the *S*.

These results suggest that there are two phenomenally describable kinds of learning that may be important in problem solving. The first variety of learning involves the acquisition by *S* of certain broad, non-specific, general notions about the properties of the object or method experienced. This was undoubtedly the case in Birch's study of chimpanzee problem

solving (1), where young chimpanzees who were initially incapable of using a stick to take distant food into reach manifested this ability after a very short period of play with sticks. It is this general, broad, nonspecific experience which seems to provide the repertoire of experience essential for productive thinking.

A second type of learning involves the acquisition of experiences which convert the initial perception of broad general properties of an object into perceptions of specific limited functional characteristics. It is this second variety of learning which appears to have occurred in the pre-utilization experiences of the Ss in our study and to have produced what Duncker (2) refers to as "functional fixedness" in problem-solving perceptions. Such fixedness limits the range of perceptual organizations capable of being developed by the *S* and so interferes with problem solving.

Summary

The present study was designed to investigate the effects of specific experience with objects in unrelated situations upon their utilizability as problem-solving instruments. The results revealed that specific prior experience limited the perception of object properties and made the experienced materials less available as problem-solving tools. These results are discussed in connection with Duncker's hypothesis of "functional fixedness," and as contributions to the general areas of transfer and of productive thinking.

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PURSUIT LEARNING AS AFFECTED BY SIZE OF TARGET AND SPEED OF ROTATION[1]

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It is common procedure to take a standard laboratory task, vary such conditions as amount of practice, rest, and spacing, and to generalize from these results. The generalization may be only to efficient techniques of learning, or it may be considered basic to a theory of learning. The question of whether the results would apply to other tasks, or even to the same task modified in certain ways, is often not raised, to say nothing of being answered.

If such generalizations are applicable to a wide range of different tasks or modifications of the same task, it is important to demonstrate this rather than to rely upon an assumption that it is so. If the generalizations must be qualified as the task is modified in different ways, it is important from a practical viewpoint to know this, but, moreover, it becomes essential from a theoretical viewpoint to understand how the modifications and the results are related.

The present study involves a limited approach to this. The task used was the Koerth pursuit rotor. It is possible to vary the difficulty of this task in at least two ways: by changing the rate of rotation of the disk and by changing the size of the target. These seem to be changes along two different dimensions, a *speed* of movement and a *precision* of movement change in difficulty. The general problem investigated was the relation between changes in these two dimensions of difficulty, and the production of reminiscence by an interpolated rest period during practice.

The early work on reminiscence has been discussed by McGeoch (**10**), and the application of the concept to the field of motor learning has been emphasized by Buxton (**4**). While there may be some question as to whether reminiscence in verbal learning is the same as reminiscence in motor learning, the present study leaves this open and is concerned only with the phenomenon in the field of motor learning.

Performance on the pursuit rotor has been the basis for much research recently, primarily because of its use by the AAF during World War II (**11**). Numerous studies have demonstrated reminiscence in pursuit rotor performance. An interpolated rest interval, particularly one introduced early in practice, produces more of a gain in score than does continued practice (**2, 3, 5, 6, 8, 12**). Likewise, results are in good agreement in demonstrating the value of spaced practice. The explanation of the facts, however, is still not agreed upon. In general, some sort of work decrement factor is assumed which accumulates with practice (**1, 6, 7**) so that the actual performance is assumed to be depressed below the level of "true" learning. When this factor dissipates with rest, we have the condition for reminiscence. There is some evidence to indicate that the depressant is not ordinary fatigue (**5**), but it is generally found to be some

[1] This report is based upon a dissertation submitted in partial fulfillment of the requirements for the Ph.D. degree, Stanford University, 1948. The author is indebted to Professor E. R. Hilgard, who directed the research, and to Professors Quinn McNemar and Donald W. Taylor for encouragement and assistance.

function of the amount of work done (2). Probably the most explicit formulation of this is found in Hull's concept of reactive inhibition (7). According to this, the greater the amount of work done, the more reactive inhibition is built up. The more reactive inhibition present, the greater the reminiscence when a rest period allows for its dissipation. It has also been suggested that the pacing of the task is important in producing the conditions necessary for reminiscence (1).

By changing the difficulty of the pursuit rotor task in the two different ways suggested, it would seem possible to learn more about these factors involved in reminiscence. Increasing the speed required to perform the task should result in more work being done in a given period of time, and this should lead to greater reminiscence. This would also involve the pacing of the task and should lead to similar results. Decreasing speed should reverse these results. In general the hypothesis presented is that a change in the difficulty of the task along the speed dimension, since it more directly influences the amount of work done in a given period, will show a greater effect upon the amount of reminiscence than will a similar change in difficulty along the precision dimension.

As the previous discussion indicates, the major interest prompting this study was the investigation of reminiscence. In the process of doing this, however, considerable other evidence was obtained as to the effect of changes in the two dimensions of difficulty upon performance. Some of this will be presented preliminary to the discussion of reminiscence.

Method

Apparatus.—The apparatus used in this experiment was a Koerth-type pursuit rotor (9). It consists of a phonograph motor mounted in a wooden box. In place of the regular turntable, a bakelite disk is mounted on the motor shaft. The circular brass target is set in this disk, flush with the surface, and with the center of the target $3\frac{1}{8}$ in. from the center of the disk. In this study three sizes of target were used, $\frac{1}{2}$, $\frac{3}{4}$, and 1 in. in diameter. Each target was mounted in a separate disk, and the disks were interchangeable on the motor mount. A friction brake and governor serve as a speed control for the motor.

The stylus is a brass rod bent in a right angle at the pointer end and with the base end hinged to a wooden handle. While the stylus is in contact with the target, a circuit is completed through a Standard Electric Timer, so that the score is the amount of time that the *S* is able to keep the stylus touching the target. A more elaborate form of the same type of apparatus used by the Aviation Psychology Program is described in detail by Melton (11).

Two sets of apparatus were used so that two *S*s could be tested simultaneously. They were placed at opposite ends of a table, and the *S*s worked facing each other. A screen 24 in. high and 36 in. wide was fastened to the back of each piece of apparatus so that one *S* could not observe the performance of the other. The *E* sat at the side of the table with the clocks facing him and between the two screens. The clocks and the data sheets were thus screened from the view of the *S*s.

Subjects.—All *S*s used in this experiment were students in undergraduate psychology courses at Stanford University. None had had previous experience with the pursuit rotor. The total experiment involved ten groups of 25 *S*s each. Each group was composed of 18 men and 7 women.

Experimental design.—Of the ten groups used, five were controls and five were experimental. The only difference was that the experimental groups were given a longer rest period at one point in practice. Otherwise, the five conditions of difficulty used were the same for both experimental and control groups, and these have been combined in certain cases where differences were not important.

All *S*s were given 20 1-min. trials. The control groups had a 1-min. rest following each trial. For the standard condition this duplicates Bell's procedure (3) which serves as a basis for comparison. The experimental groups had a 5-min. rest following trial 5 and a 1-min. rest following all other trials.

The five conditions of difficulty used were: (1) a standard condition of the usual size target and the usual rate of rotation for this test, (2) a slower rate with a standard size, (3) a larger

TABLE I

CONDITIONS OF DIFFICULTY

Description	Rate of Rotation (rpm)	Diameter of Target (in.)	Symbol
Standard	60	$\frac{3}{4}$	60-M
Easier rate	50	$\frac{3}{4}$	50-M
Easier size	60	1	60-L
Harder rate	80	$\frac{3}{4}$	80-M
Harder size	60	$\frac{1}{2}$	60-S

size with standard rate, (4) a faster rate with standard size, and (5) a smaller size with standard rate. These are summarized in Table I with the exact size and rate values and with a symbol which will be used to designate the condition. The number in the symbol refers to the rate of rotation, the letter to the size of target: Medium, Large, or Small.

These particular values were selected in order to meet certain requirements for the measurement of reminiscence. Under the present experimental conditions, reminiscence is shown by a greater gain between trial 5 and trial 6 for the experimental group than for the control. It is a difference score, and in order to compare amounts of reminiscence under different conditions, some assumption about the equality of the units of reminiscence is necessary. The assumption of equality is probably adequate as long as reminiscence is being measured from a common base of performance, but if performance scores are quite high under one condition and quite low under another, the assumption that equal differences in scores mean equal amounts of reminiscence may be seriously in error. The main concern of the present investigation is to compare reminiscence under different *dimensions* of difficulty. There are two easier-than-standard conditions and two harder-than-standard conditions. If these conditions are so arranged that performance at trial 5, just prior to the interpolated rest, is equal for the two more difficult conditions and is also equal for the two less difficult conditions, the relative effect of altering the two conditions can be studied. It may not be possible to compare the amount of reminiscence in the easier conditions with that in the more difficult conditions, but that is not the major interest. So the alterations in size and rate were selected on the basis of preliminary work to meet these requirements and also to be sufficiently different from the standard conditions to be meaningful.

The *S*s were assigned to the groups in random order, subject to certain practical limitations. Seventy-five *S*s served under control conditions as part of the preliminary standardization of conditions before testing of any experimental groups was begun. Other limitations were: not being able to test a control and an experimental *S* at the same time, the lack of sufficient equipment to test two *S*s under the same condition of size, the desire to have the same number of men and the same number of women in all groups, and the difficulty of securing two *S*s for every experimental period. Approximately half the *S*s were tested individually, half in pairs. No attempt was made to equate the groups in terms of initial score, although one *S* was dropped from a group because of a score far below the rest of the group and evidence of no real attempt to learn.

Conduct of the experimental session.—The *S*s were given brief oral instructions by *E* as he demonstrated the task. They were told that it was a difficult task and not to be surprised if they thought they were doing poorly at first. They were instructed to be as relaxed as possible and not to press down too hard on the stylus, but otherwise no specific directions as to the most efficient technique were given. The *S*s knew that there would be 20 1-min. trials with 1-min. rest periods between, and the experimental groups were told that they would have one longer rest period. No information was given during the course of the experiment as to score made or as to the number of trials completed or remaining. The only suggestions made to the *S*s after the initial instructions were in cases where these instructions were not being followed. At the completion of the 20 trials they were allowed to see their results, as they had been promised initially.

The following procedure was used for each trial. The *E* said, "Ready," about 5 sec. before the trial began. On this signal, *S* placed the stylus in the center of the disk. Approximately 2 sec. before the trial began, *E* started the motor which turned the disk. This was the signal for *S* to begin following the target. At the beginning of the trial proper, *E* closed a switch in the timer circuit and opened it 1 min. later. The motor was then stopped, and the *S* rested until the procedure was repeated. This was continued through the course of the experiment, the only exception being the 5-min. rest period for the experimental groups after trial 5. During the rest periods the *S*s conversed with *E* or each other, read in a few cases, or simply rested quietly. The *S*s performed the task while standing, but were allowed to sit down to rest between trials. The *E* recorded the time on the target for each trial in tenths of a second. Because each *S* served but once, all *S*s were dismissed at the end of the period without further instructions.

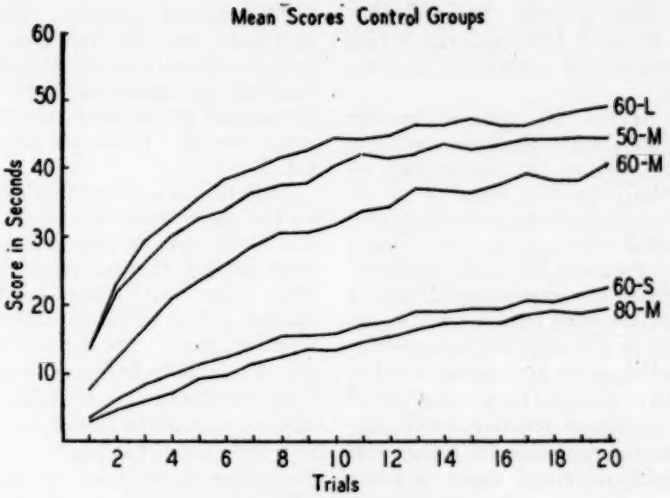

FIG. 1. Mean scores by trials for control groups under five conditions of difficulty. $N = 25$ for each group.

RESULTS

The results to be presented give, first of all, the general changes produced in the course of learning when difficulty is changed in the two specified ways: in speed and in precision of movement required. Mean score changes or typical learning curves, changes in variability, and analyses of scores as a function of area of target and rate of rotation are included in this. The effect on reminiscence is then considered. Finally the effect of the altered conditions on individual consistency is presented.

Mean scores.—Figure 1 presents graphically the mean scores by trial for each control group. At the fifth trial the groups under the two easier conditions (60-L and 50-M) are not significantly different from each other, nor are the groups under the two harder conditions (60-S and 80-M).[2] The easier conditions give scores significantly above those for the standard; the harder conditions give scores significantly below those for the standard. The conditions employed meet the requirements previously specified, and when comparable units are employed, the scores for the standard difficulty are quite similar to those presented by Bell (3).

Inspection of the curves in Fig. 1 yields little indication that the two dimensions of difficulty being studied have any marked differential effect on the changes in performance with practice. The two easy conditions do start out almost indentically and then diverge during the first few trials. Comparing the actual gain from first to last trial, the t of 60-L

[2] For tables of means and standard deviations for all groups on each trial of learning order Document 3228 from American Documentation Institute, 1719 N St., N.W., Washington 6, D. C., remitting $1.00 for microfilm (images 1 in. high on standard 35 mm. motion picture film) or $1.00 for photocopies (6 × 8 in.) readable without optical aid.

minus 50-M is 2.45. That for 60-S minus 80-M is 1.07, and the curves for these harder conditions are very similar.

The curves for the comparable conditions are not identical, and there is some evidence that gains may be more rapid for 60-L than for 50-M, but no very significant evidence of any differential effect of the two dimensions of difficulty has been produced. Data from the experimental groups substantiate these results (see Fig. 4). Changes in difficulty as measured by mean group score are similar whether difficulty is changed by varying size of target or rate of rotation within the limits of the experimental conditions.

Variability.—Since there was no evidence of any consistent effect of the interpolated rest period on variability, results for experimental and control groups have been combined and presented together. Standard deviations for the combined group under each condition of difficulty were obtained by combining the sums of the squared deviations from their own group means. These are plotted in Fig. 2.

Analysis of the standard deviations for the three conditions 50-M, 60-L, and 60-M reveals that variabilities show similar changes from trial to trial under all these conditions. There is a short initial rise followed by a gradual drop. The rise comes later, and the drop is less pronounced for 60-M, but the pattern is similar. The reduced variability in the later trials is to some extent, at least, a result of the ceiling of the test. While no *S* achieved a perfect score of 60 on any trial, a substantial number of the *S*s approached this. This indicates that the change in variability found under

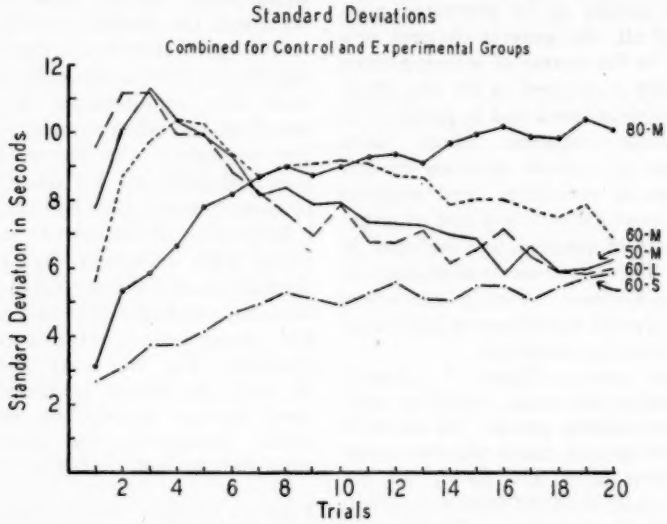

FIG. 2. Combined standard deviations for control and experimental groups under five conditions of difficulty. The sums of the squared deviations around the group mean for the experimental and for the control groups were combined to obtain the standard deviations for each trial. Each combined standard deviation is based on 50 cases.

these conditions is at least partially an artifact of the ceiling of the task and that no general conclusions can be drawn about the basic problem of what happens to individual differences with practice in other situations. In spite of the reduced variability at the end of practice, individual consistency of performance remains high, as the correlations presented in Tables III and IV indicate.

Altering the two dimensions of difficulty to produce easier conditions has no differential effect on variability. In fact it changes variability very little from that for the standard conditions. This conclusion does not apply to the more difficult conditions, however. No ceiling effect is apparent for groups 80-M and 60-S. If anything, just the opposite is true. The scores are positively skewed for the first few trials so that there may be an artificial floor at the low end of the score scale. In any case, variability increases throughout the 20 trials for the groups under these more difficult conditions.

The results also indicate differences between the two dimensions of difficulty at this end of the scale. The standard deviations for the faster rate increase much more rapidly than do those for the smaller size, although the changes in mean score were very similar. This indicates, of course, that the faster rate actually produced greater individual differences, some individuals catching on rapidly and performing very well, others making very little progress throughout. The smaller size in contrast produced neither the very high scores nor the very low ones. Here is the first indication that different psychological functions underlie adjustment to rate and to size.

The following explanation of this is offered, based partly on the actual observation of the Ss in the experimental situation. Apparently there are two phases involved in acquiring pursuit rotor skill. The first is the development of an over-all circular movement of the arm. Once this has developed, there can be a refinement of the movement into the limits set by the target. While the two phases overlap, the first must precede the second to some extent.

At speeds of 60 rpm and less, most college students seem to be able to master the first phase reasonably well and progress into the refinement phase. At 80 rpm, some of them evidentally never develop the relatively smooth arm movement but continue to follow the target with awkward jerks and large overcorrections. The result is little improvement during the 20 trials. For others the 80-rpm rate is not too fast, the awkward phase is passed through, and the target size used is sufficient to allow the development of the refinement phase to a high degree for these individuals. At 60 rpm with a smaller target (group 60-S), the first phase is not such a problem, but the small target prevents the relatively high scores made by some individuals in group 80-M. This would account for the differences in variability found.

The above implies that the function relating rate and difficulty shows a sudden change somewhere in the vicinity of 80 rpm, but that this value is different for different individuals. Furthermore, rate is primarily important in the development of the first phase of performance. The relation between size and difficulty is important in the second phase and shows a much smoother function. This analysis seems to fit both the observations of performance and the analysis of scores and may have

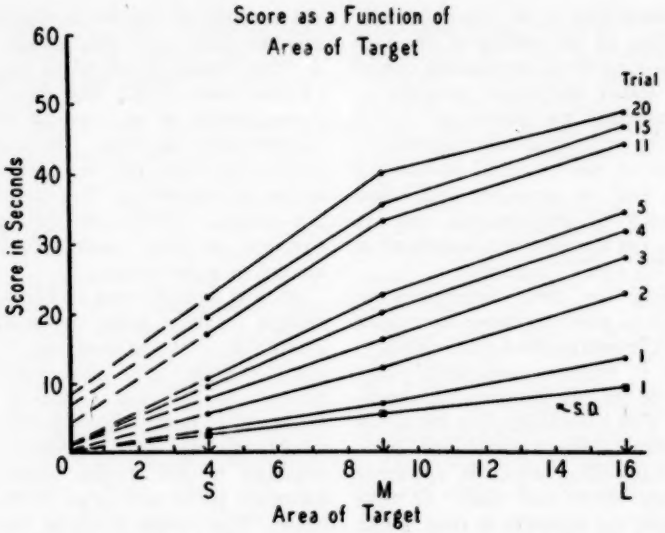

FIG. 3. Score as a function of area of target. The units of the base line are square inches multiplied by $64/\pi$. Mean scores for several trials are plotted above the value for the size of target with which they were obtained. Scores are for experimental and control groups combined, and those for the same trial are connected by a line. The bottom line plotted on the graph represents the corresponding standard deviations for trial 1. $N = 50$ for each combined group.

implications for training in tasks which involve variations of these two dimensions. The generality of this needs to be established, as well as the answer to such questions as whether the rate involves difficulty of performance or simply difficulty of acquisition.

Relation of scores to area of target and to rate of rotation.—An examination of the relations between size of scores and area of target provides additional information. Figure 3 portrays this relationship graphically. The base line represents the area of the target in units of square inches multiplied by $64/\pi$. In these units the small target has an area of 4, the standard has an area of 9, and the large target has an area of 16. Each line of the graph connects the score for the three conditions on the same trial. Experimental and control groups have been combined.

It is apparent that for the first three trials at least, size of score is a straight-line function of the area of the target. If the line is extrapolated downward toward the base line, it reaches approximately zero score at zero area. This is taken as evidence that there is little difference in actual behavior of the *S*s for their first few trials as a function of the size of the target. Size enters only as a scoring device. The *S*s could be responding in the same way to all targets, but those using the smaller targets would make lower scores simply because there is less available area for contact. The scores are just what we would predict if the probability of hitting the target were directly related to the area of the target. This would seem to substantiate the analysis of the preceding section.

After the first few trials the linear

relationship disappears. How much of this is the result of the test ceiling under the easier conditions and how much of this is a reflection of actual differences in the behavior of the *Ss* cannot be answered from the data. One approach to an answer would be to shift *Ss* from easy and from hard conditions to the standard size at various points in practice and compare their performance under these new conditions.

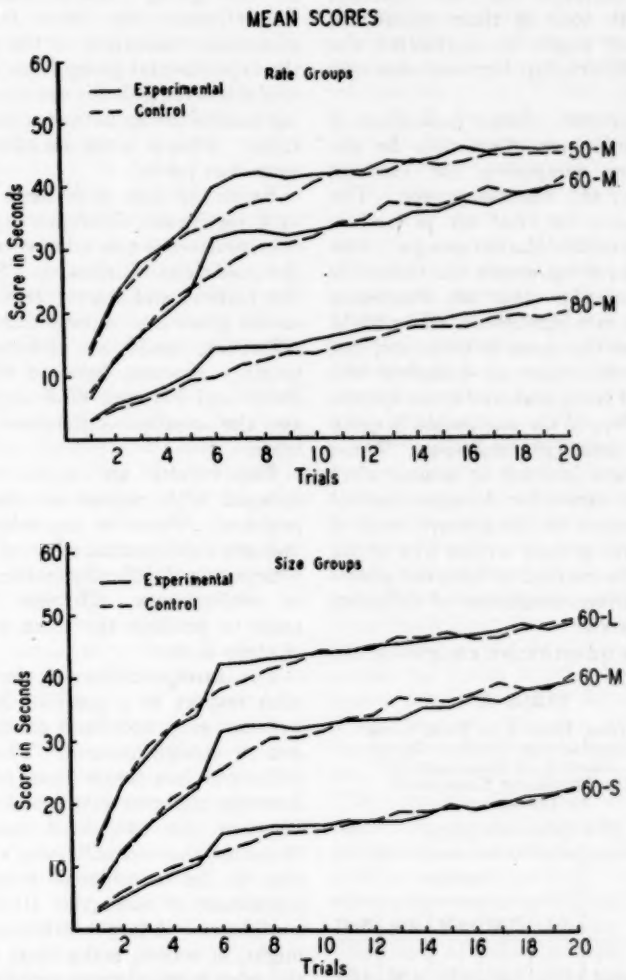

FIG. 4. Mean scores by trial for all groups. Groups 60-M are common to both rate and size sets and so are plotted twice. The experimental and control groups differ in that the former had a 5-min. rest after trial 5 instead of the usual 1-min. rest. Scores are time that the stylus was touching the target during a 1-min. trial. $N = 25$ for each group.

An analagous study of the relation between scores and rate of rotation was attempted. No single choice of a unit for the base line seemed best a priori, so various units were tried. No very different interpretations seemed indicated for the different units, but none of them seemed to offer what might be considered the "real" relationship between rate and score.

Reminiscence.—Some indication of the reminiscence effect may be obtained by comparing the learning curves for the various groups. The mean scores by trial are plotted in Fig. 4 for each of the ten groups. One set of curves represents the three size conditions; the other set represents the three rate conditions. The 60-M groups are the same in both sets, but are plotted twice to complete the picture of three sizes and three speeds.

The effect of the rest period is quite apparent under all conditions. There is a marked increase in scores, after which the curves for the experimental groups return to the general level of the control groups within five or six trials. No marked differential effects of the various conditions of difficulty are indicated.

A more quantitative analysis of the reminiscence effect is possible than is provided by inspection of the curves. Table II presents the actual gains for both control and experimental groups from trial 5 to trial 6, the amount of reminiscence and the standard error of the group reminiscence score. Reminiscence has been taken, as previously indicated, as the gain for the experimental group from trial 5 to trial 6 less the gain for the corresponding control group between these same trials. Thus it is the net effect of the extra rest period.

TABLE II

GAINS FROM TRIAL 5 TO TRIAL 6 FOR EXPERIMENTAL AND CONTROL GROUPS AND AMOUNTS OF REMINISCENCE UNDER DIFFERENT CONDITIONS OF DIFFICULTY

(N = 25 for each group)

	Condition				
	60-L	50-M	60-M	60-S	80-M
Group					
Experimental	7.74	6.10	8.95	4.98	4.06
Control	2.68	1.53	2.48	1.13	.70
Reminiscence	5.06	4.57	6.47	3.85	3.36
SE_{Rem}	1.48	1.22	1.06	1.01	.84

From the data it is clear that no very significant difference in amount of reminiscence exists between any of the conditions of difficulty. Selecting the highest and lowest reminiscence scores gives a t of only 2.3 for the difference, and the differences of primary concern, between 60-L and 50-M and between 60-S and 80-M, are the smallest differences in the table.

The results are quite straightforward with respect to the major problem. There is no evidence to indicate a differential effect of the two dimensions of difficulty on the amount of reminiscence. Changes in rate seem to produce the same results as changes in size.

The interpretation of the results with respect to a possible difference between easy and hard conditions is not so straightforward. The actual differences are larger than are those between the two easy conditions or between the two hard conditions. However, they are still not of sufficient size to be considered statistically significant at even the .05 level of confidence. A larger number of cases might, of course, make them so. On the other hand, the real problem is the one previously mentioned, the question of the comparability of the scale units at the easy end of the scale to

those at the more difficult end. Possibly if "true" units of reminiscence were used, a difference could be established, although it might equally well reduce any apparent difference now present.

A number of methods have been attempted to determine whether the conclusions reached depend specifically upon the scale used. None of the several methods tried has produced any significant change in conclusions. Relative reminiscence scores based on the mean score at trial 5, on the physical conditions of difficulty such as area of target or time per revolution, and on the variability of the raw scores at trial 5 have been employed without altering the basic conclusion that no significant differences result from the variables employed in this study.

The possibility of still another scaling device's producing differences cannot be rejected. All that can be said is that within the reasonable range of techniques employed, the conclusions are independent of the method used to compute reminiscence scores. No significant effect of degree of task difficulty on amount of reminiscence has been found.

More specifically, there is no evidence to support the hypothesis that changing the rate of performance would affect reminiscence more than changing the precision required. This does not confirm the relationships assumed to exist between amount of work, reactive inhibition, and reminiscence. Neither does it support other explanations involving fatigue or pacing. The present experiment is not crucial to the entire concept of reactive inhibition, but it at least requires some explanation of why the apparent change in amount of work done does not result in changes in reactive inhibition and reminiscence. Particularly is an explanation needed to consider that more time spent working does provide more reminiscence (2), but more work done in a given period of time does not.

A possible objection may be raised that evidence has been previously presented indicating that the actual behavior of the *S*s in precision of movement may not be affected during the first few trials by changing target size. It is not clear how important this is by the fifth trial. If differences in precision are not involved, it would indicate that only one dimension has effectively been altered. Changing the rate obviously changes the speed of behavior during a trial. Speed of movement remains constant when size of target is changed and rate held constant. Perhaps all this change does is to provide a comparable score to serve as a base from which to compute reminiscence. This may actually strengthen the argument, if it is correct, since it would insure that a change in the so-called precision dimension did not introduce its own increased fatigue or reactive inhibition. Introduction of the rest pause later in practice might provide further information, but the approach to the test ceiling of the *S*s under the easy conditions would interfere with adequate interpretation. Whether two dimensions of difficulty have been changed or whether only one has been, the interpretation seems to stand. The expected differences in reminiscence have not been found.

Individual consistency.—The last problem to be considered is that of the consistency of individual performance as affected by the different conditions of difficulty and the presence or absence of extra rest. Table III gives the correlation coefficients between certain successive trials and between first and last trials. From

TABLE III

CORRELATIONS BETWEEN SELECTED SUCCESSIVE TRIALS AND BETWEEN INITIAL AND FINAL TRIALS

Group	Trials			
	1 and 2	3 and 4	19 and 20	1 and 20
60-L Exper.	.92	.90	.89	.66
Control	.81	.95	.88	.55
50-M Exper.	.92	.92	.80	.47
Control	.93	.93	.93	.65
60-M Exper.	.83	.96	.84	.73
Control	.92	.93	.90	.57
60-S Exper.	.84	.89	.71	.60
Control	.89	.83	.83	.34
80-M Exper.	.78	.90	.97	.74
Control	.90	.97	.94	.47

this it is evident that there is sufficient consistency from one trial to the next to indicate that the scores are reliable measures of individual differences on this particular task at a given stage of practice. Likewise, the degree of consistency does not seem to depend in any special way upon the conditions of difficulty. As would be expected, the correlations between the first and the last trials are below those for the successive trials, but they are high enough to indicate that at least some of the factors producing good performance on the first trial are still involved in the later trials.

The correlations which might be expected to show differential effects of the rest period are given in Table IV. The experimental and control groups have almost the same correlations between trials 5 and 6, with the exception of groups 60-S. No explanation for this discrepancy is apparent other than the lower standard deviations for these groups. When the results for all experimental groups are pooled and compared with those for the control groups, there is no significant difference. The average correlation (z-transformation) for experimental groups is .87, and for the controls, .90. The t for this difference is less than 1. The correlations between trials 1 and 20 show rather wide but inconsistent fluctuations from experimental to control groups. None of the differences between experimental and control groups for the same condition of difficulty is significant at the .05 level, nor is the difference between the means of the correlations.

The correlations between actual gain from trial 5 to trial 6 and the

TABLE IV

EFFECT OF REST PERIOD ON INDIVIDUAL CONSISTENCY

Group	Correlation between Trials			
	5 and 6	1 and 20	1 and Gain	20 and Gain
60-L Exper.	.85	.66	−.33	−.07
Control	.87	.55		
50-M Exper.	.91	.47	−.40	.21
Control	.90	.65		
60-M Exper.	.90	.73	−.33	−.32
Control	.96	.57		
60-S Exper.	.57	.60	.21	.50
Control	.80	.34		
80-M Exper.	.95	.74	.13	.36
Control	.92	.47		
Mean (z-transformation)				
Exper.	.87	.65		
Control	.90	.52		

initial score and the final score, are also presented in Table IV. Only one of the ten coefficients is significant at the .01 level, and one other is significant at the .05 level. There is a slight indication from the trend of the coefficients that for the easier conditions, high gains are associated with low levels of performance, and for the harder conditions, high gains are associated with high levels of performance. The fact that some of the best performers under the easy conditions were approaching the ceiling of the test and hence artifically restricting their possible gain may be indicated. Actually all we can say is that the gain over the 5-min. rest period is relatively independent of either the initial or the final status of the individual.

Summary

1. Ten groups of 25 *Ss* each were tested under five conditions of difficulty on a Koerth-type pursuit rotor. The conditions of difficulty were arranged to alter either rate of rotation or size of target while holding the other constant. Two easier-than-standard conditions, a slower rate and a larger size, and two harder-than-standard conditions, a faster rate and a smaller size, as well as the standard conditions, were used. Two groups were tested under each condition, one an experimental, the other a control. The controls had 20 1-min. trials with 1-min. rest periods between each. The experimental groups were similar except for a 5-min. rest between trials 5 and 6. Scores were amount of time the stylus was kept on the target.

2. Learning curves indicated little difference between decreasing the difficulty of the task by either of the methods or between increasing the difficulty by either of the methods.

3. Changes in variability are similar throughout practice for the easier and for the standard conditions. They are markedly different for the more difficult conditions, and variability increases more rapidly when the rate is increased than when the size is decreased. An analysis of the learning task which accounts for this is offered.

4. During early trials there is a direct linear relation between area of target and size of score, which, extrapolated to zero area, predicts zero score. This relation no longer holds after the first few trials.

5. Reminiscence, or gain over an interpolated rest period, does not appear to be significantly different under any of the conditions used in this experiment. No significant differences were found between the two dimensions of difficulty or between the easier and harder conditions. Various scale alterations failed to change these conclusions. Because of this lack of differences some modification of the explanation of reminiscence in terms of reactive inhibition seems necessary. The importance of pacing is also questioned.

6. The trial-to-trial correlations indicate an adequate degree of reliability of measurement. None of the conditions of difficulty, nor the addition of an extra rest period, seems to have any consistent effect on the degree of individual consistency. Gains over the extra rest period are relatively independent of initial or final score status.

7. The general conclusion reached in the total investigation is that the two dimensions of difficulty, speed and precision, as here studied have a differential effect on performance primarily in their effect on individual differences at the more difficult end of the scale.

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ELECTRORETINAL AND PSYCHOPHYSICAL DARK ADAPTATION CURVES [1]

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The development of more convenient methods for recording the electrical responses of the human eye when it is stimulated by light has awakened renewed interest in comparisons between electroretinal and psychophysical data.

Certain parallels have long been recognized. Dewar and McKendrick (4, 5), as well as Holmgren (9), pointed out more than seventy years ago that the midspectral wave lengths, which appear most brilliant to the human eye, are also most effective in evoking electrical responses; and it was Kühne and Steiner (13) who first reported that light adaptation reduced the amplitude of the response while dark adaptation restored it.

More recently, Adrian (1, 2) has identified the major component of the response, the *B-wave*, with the *scotopic* visual system. A recent study by Riggs, Berry, and Wayner (15) has borne this out, demonstrating that the effectiveness of light of different colors in arousing the electroretinal response follows the scotopic pattern closely. Even under conditions of moderate light adaptation there is no Purkinje shift.

Two papers have lately been concerned with the possibility of demonstrating a relationship between electroretinal and psychophysical measures of the course of dark adaptation. In the first of these, Karpe and Tansley (11) present data which purport to show a remarkable parallelism of the two types of data. In the second, Johnson (10), while concluding that the *B-wave* is of scotopic origin, points out specific difficulties in the way of making direct comparisons between electroretinal and psychophysical "dark adaptation curves."

Karpe and Tansley measured the electrical response to a flash at intervals during the course of dark adaptation. The flash was of constant intensity and, presumably, of constant duration, though their published records show what appears to be a variation between the limits of 40 and 70 msec. The retinal response to this test flash rose from a value near zero at 8 min. to about 300 microvolts after 50 min. of dark adaptation. During the same period of dark adaptation the light threshold was determined at intervals, using considerably dimmer flashes applied to the periphery of the same eye. From the data so obtained, a conventional dark adaptation curve was plotted. The electrical and the psychophysical data were then plotted, together, on a graph whose abscissa denoted time in the dark. Ordinate values for the psychophysical data represented absolute threshold on a logarithmic scale of intensity. For the electrical data, the ordinate values consisted of measures of the magnitude of the re-

[1] This research was carried out in the Psychology Laboratory of Brown University under Contract N7onr-358, Task Order II, between the ONR and Brown University.

sponse to the constant test flash. This scale was inverted and adjusted so that zero response fell at the level of the rod-cone break in the threshold curve (on the assumption that the rods were not functioning earlier) and so that 300 microvolts, the response recorded at the end of the session, coincided with the final level of the psychophysical threshold. This manner of plotting the data gives the appearance of practically identical curves. Karpe and Tansley themselves acknowledge, however, that log intensity and "microvolts below zero" have no fixed rate of exchange as measures of sensitivity. They say, in a closing sentence, "Theoretically a more satisfactory comparison between the subjective and the E. R. G. (i.e., electrically determined) curves would be obtained if the latter represented the stimulus intensity necessary just to evoke a *b*-potential at different times during dark adaptation."

The above-mentioned procedure was, in fact, the one employed by Hartline (**7**) in *Limulus*, by Riggs (**14**) in the frog, and by Johnson (**10**) in man. Hartline showed that, in his invertebrate preparation, the curves relating magnitude of electrical response to logarithm of stimulus intensity were straight lines, essentially parallel to one another. Hence he could fairly present the course of adaptation by showing the rise in the electrical response to a stimulus of a single intensity. In the vertebrate eye, however, no such simple relationship exists (**14**). The data of Johnson, moreover, reveal that the shape of a curve such as that presented by Karpe and Tansley—obtained by plotting magnitude of response against time in the dark for a single flash intensity—may vary with the intensity of the flash selected. It appears, therefore, that the close similarity between psychophysical and electrical data reported by Karpe and Tansley is almost fortuitous; it is certainly specific to one set of experimental conditions.

Johnson recorded retinal responses to 0.04-sec. flashes over a wide range of intensities, providing data of the sort recommended by Karpe and Tansley in their statement quoted above. Curves were derived showing the gradual decrease in the flash intensity required to elicit a *B-wave* of constant magnitude as dark adaptation progressed. Instead of a single "electroretinal dark adaptation curve," however, there was obtained a family of such curves differing in shape and each representing a particular response magnitude. In view of the differences among these curves it seemed unprofitable to select any one of them for direct comparison with the psychophysical threshold curve—especially since even the lowest curve (representing intensities required to elicit a barely measurable *B-wave*) had been obtained with flashes *more than four log units above absolute threshold levels*.

One cannot help being curious, however, as to what a psychophysical curve might look like, set alongside such electroretinal results as have been obtained. The present paper makes this juxtaposition. A threshold curve is presented for the same *S* who served in the electrical study, with conditions identical save that the intensities of the stimuli are reduced to threshold levels.

In addition, a "brilliance-equation" technique, to be described shortly, has been employed to obtain a sort of "dark adaptation curve" at the higher stimulus levels employed in the electrical study. There are good reasons for doubting that either of these two

procedures represents what we should call the "true psychophysical correlate" of the electrical data. It is thought, however, that their publication may aid the thinking of those who like to search for such correlations.

Apparatus and Procedure

In both the threshold and the "brilliance-equation" procedures, the basic apparatus and experimental design were as described by Johnson (10). Sessions began with 45 min. of dark adaptation followed by 15 min. of exposure to an adaptation field at 1.73 footlamberts. Testing began with the close of this pre-adaptation. The adapting field was circular, extending nearly to the limits of the visual field. The stimulus subtended 7° 30′ and was viewed centrally with the right eye. The stimulus was white light from a 3300° K tungsten source. Flash duration was .04 sec.

Psychophysical threshold procedure.—For measuring psychophysical thresholds it was necessary to reduce the intensity of the test flashes to values much lower than those used in eliciting electrical responses. Figure 1 shows the manner in which the basic apparatus was modified to achieve this result. The position of the eye was changed from *P*, where it had been in the electrical study, to *E*. Unsilvered glass mirrors, M_1 and M_2, reflected a small fraction of the light diverging from point *P* so that the subject obtained a Maxwellian view of the lens, *L*. An aperture at *A* reduced the stimulus to the required diameter of 7° 30′; and a third glass mirror, M_3, served to introduce a fixation point, reflected from *FP*. The reduction in intensity of light between *P* and *E* amounted to 4.5 log units. The net effect of these changes was such that the experimenter used, at *F*, Wratten neutral filters of the same order of density as

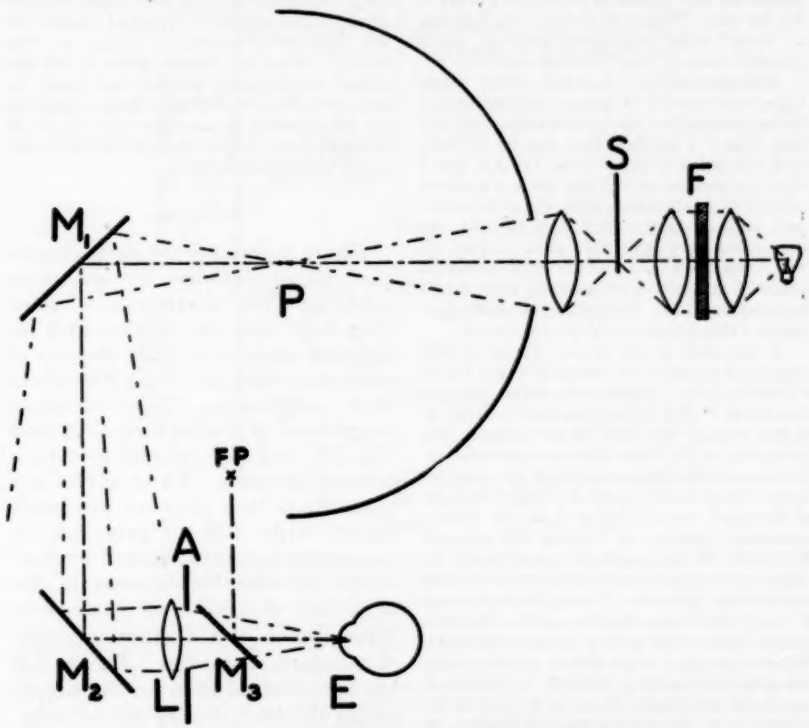

Fig. 1. Apparatus for determining psychophysical thresholds

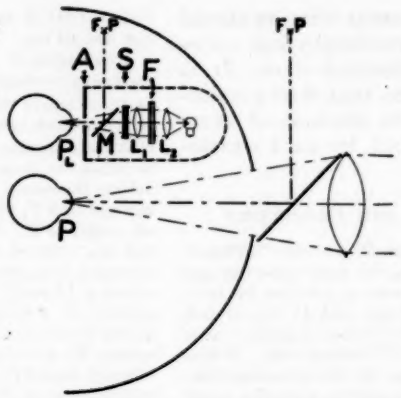

FIG. 2. Apparatus used in "equated brilliance" determinations

were employed in the electrical study. Flash intensities were varied in filter-density steps of 0.1 log unit. Flashes were presented, following a "ready" signal, at frequent intervals, and *S* reported them as "seen" or "not seen."

Brilliance-equation procedure.—This technique called upon *S* to compare the brilliance of flashes presented to the dark-adapting right eye with that of a standard flash seen by the fully dark-adapted left eye. Craik (3) has noted that it is possible to hold one eye in a constant state of dark adaptation while the other undergoes various changes in adaptation. In this experiment both eyes were dark adapted 45 min., after which time the right eye only was exposed 15 min. to a light-adapting field of 1.73 footlamberts. The left eye remained dark adapted throughout the whole experiment.

At the close of the 15-min. period of light adaptation the light was extinguished and *S* took a position, using a biting-board, so that the right eye was at *P* (Fig. 2) ready to be stimulated by flashes through the main optical system. The left eye was at P_L, oriented to receive stimulation from an auxiliary system consisting of a tungsten source; lenses L_1 and L_2, which focussed the light at the pupil; camera shutter *S*, set for .04-sec. exposures; aperture *A*, limiting the stimulus field at 7° 30′; and unsilvered glass mirror *M*, which introduced a fixation point similar to that used for the right eye. During the experiment *S* fused these two fixation points. Wratten neutral density filter *F* fixed the intensity of the left-eye flash at a value closely approximating the minimum intensity required to produce a measurable electrical response in the fully dark-adapted eye. In making his comparisons, *S* was presented with three flashes spaced about 1 sec. apart. The first was the standard (left eye), the second the test flash (right eye), the third another standard. *S* judged whether the test flash was "brighter," "equal," or "less bright." Since the fixation points in the two optical systems were centered and fused, the subjective effect was of three flashes occurring, one after another, in the same spot. As in the threshold study, brightness of the test flashes was varied in 0.1 log unit steps.

RESULTS

Figure 3 presents the dark adaptation curves obtained by the three methods. The electroretinal curves (Fig. 3-B) show the relative flash intensities required to elicit *B-waves* of constant amplitude during 100 min. of dark adaptation. Three criterion magnitudes of *B-wave* have been used (50, 100, and 200 μv) and a curve is plotted for each. These curves are taken from the data of Johnson's earlier study (**10**). Figure 3-A reproduces the relevant figure from that study, showing the increase in the amplitude of the *B-wave* response to white stimuli of a number of grades of standard intensities. Figure 3-B has been derived from 3-A by simply noting the filter density values corresponding to each of the three magni-

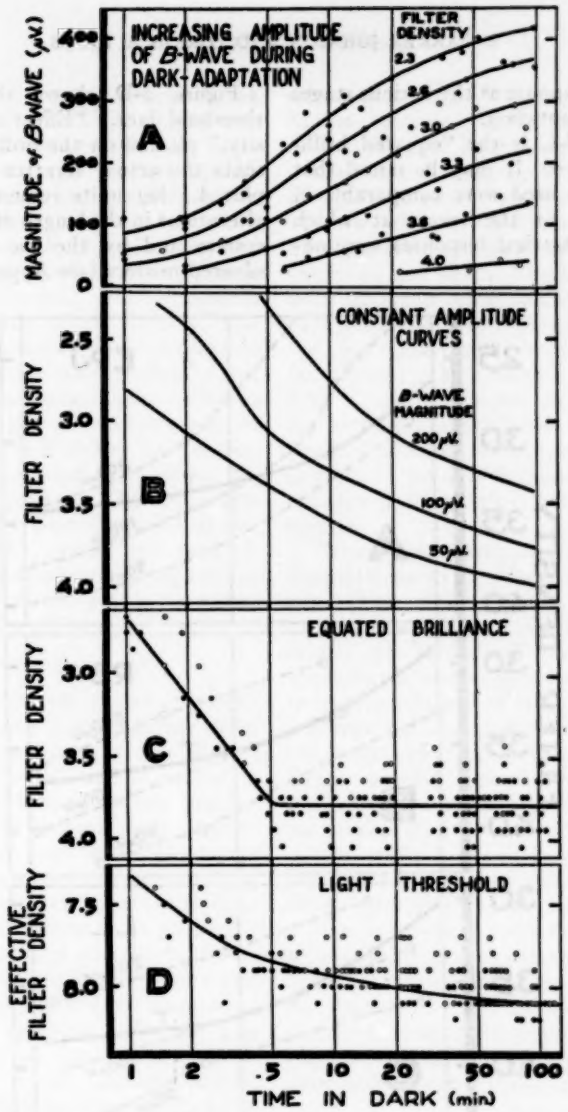

FIG. 3. Dark adaptation curves for subject EPJ. Graph A shows electrical response magnitudes upon stimulation with white light of six different standard intensities at intervals during dark adaptation. The curves in Graph B are obtained by reading off, from Graph A, the strength of the stimuli required to obtain responses of three standard magnitudes: 50, 100, and 200 microvolts. Graph C is a plot of the responses obtained during the "equated brilliance" study. Open circles represent judgments of *greater*, filled circles judgments of *less* brilliance of the test flash, as compared with the standard flash. Half-filled circles represent judgments of *equal*. Graph D is a plot of the responses obtained for determination of the absolute light threshold. Open circles represent responses of *seen*, filled circles of *not seen*. All curves are fitted by eye. An indication of the absolute value of the flash brightnesses is given by the fact that Filter Density 5.2 produces a flash field which matches the light adaptation field (1.73 footlamberts).

tudes of response at the various stages of dark adaptation.

Figure 3-C is the "equated brilliance" curve. It may be noted that the flashes used were comparable in brightness to the levels at which minimal electrical responses were observed.

Figure 3-D shows the absolute threshold data. "Effective filter density," plotted on the ordinate, represents the actual Wratten filters used plus 4.5 log units reduction by the alterations in the length of the optical system and by the use of the unsilvered mirrors (see Apparatus).

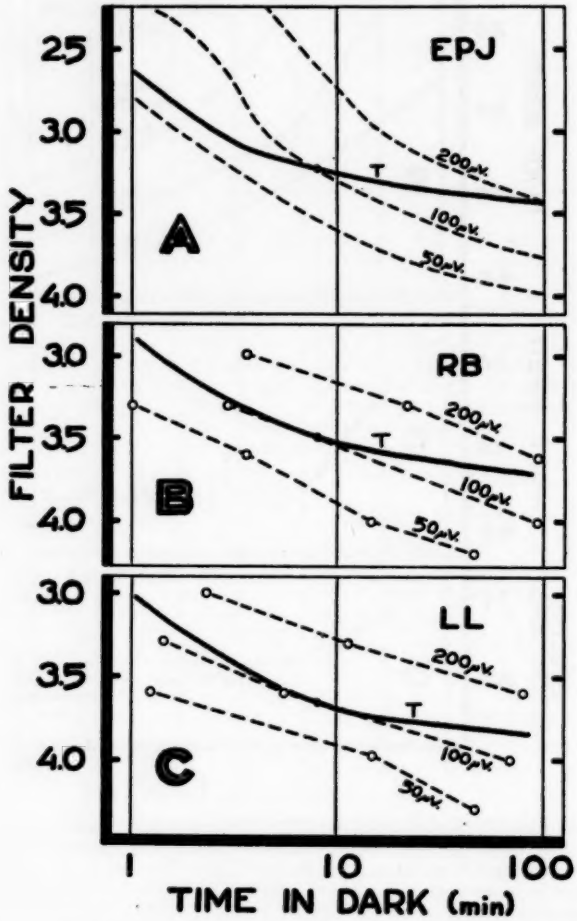

FIG. 4. A comparison of electrical and psychophysical curves for three *Ss*. In Graph A the electroretinal (Fig. 3-B) and psychophysical (Fig. 3-D) dark adaptation curves of EPJ are superimposed. The threshold curve has been raised on the ordinate to match the 100 μv electrical curve at 8 min. Graphs B and C represent similar comparisons for two additional *Ss*.

Each of the psychophysical curves represents data obtained during two complete sessions, recorded on separate days. In the plotting of the points no distinction has been made between sessions.

In Figure 4-A the electroretinal and psychophysical (threshold) data are superimposed. The threshold curve has been raised about 4.7 log units on the intensity axis to coincide with the 100 μv electroretinal curve at 8 min. of dark adaptation. Figures 4-B and 4-C present similar comparisons for two additional *S*s. Procedures were identical with those described for subject EPJ but were limited to one electroretinal and one psychophysical session for each *S*. They are offered as confirming certain observations to be drawn from the data of subject EPJ.

Discussion

We find ourselves unable to concur with Karpe and Tansley in the belief that the magnitude of the *B-wave* during dark adaptation is related in some simple fashion to the psychophysically determined light threshold. Whether one considers, as the electrical measure, the *magnitude of the response* to some standard flash or the *brightness* necessary to produce a *B-wave* of standard magnitude, differences between the electroretinal and the psychophysical dark adaptation curves are apparent. We do not, however, regard these differences as prejudicing, in the slightest degree, the now general assumption (**1, 2, 10, 11, 15**) that the *B-wave* manifests scotopic activity.

In comparing the various curves we have presented, we may begin by disposing of the equated brilliance curve (Fig. 3-C). Its value is, perhaps, to emphasize the fact that the stimuli used were far above the absolute threshold. We see that these flashes increased in brilliance only during the first 7 min., although the sessions lasted 90 min. We recognize this pattern immediately and attribute the observed brilliance to the photopic system. Although the electroretinal and equated brilliance data were obtained with stimuli of comparable brightnesses, it is evident that the very considerable development of the *B-wave* which occurs *after* the first 7 min. finds no psychophysical correlate in brilliance. In other words, brilliance at photopic levels appears to be uninfluenced by large changes in the activity of the scotopic system.

We may next compare the absolute threshold curve with the electrical results (Figs. 3-B, 3-D, 4). We see that the magnitude of the *B-wave* chosen as a "standard" may have an effect on the electrical curve; it seems to be generally true of all these curves, however, that they are steeper than the psychophysical curve. In particular we may note that sensitivity, by electrical criteria, is still progressing markedly at the end of the experimental period of dark adaptation while the psychophysical threshold shows a tendency to level off.[2]

Now we consider some reasons why we should not expect strict parallelism between the electrical and psychophysical data. The absolute threshold curve reveals the amount of light required to excite the scotopic visual system liminally at any given time

[2] We should note here that the eye was not, during the psychophysical threshold determinations, subjected to the periodic bright flashes which punctuated the sessions devoted to the recording of the electrical responses. Controls, showing that presentation of a series of flashes at 1-min. intervals does not alter the size or form of *B-waves* obtained subsequently, indicate that the electrical curve is not distorted by the procedure used.

after the beginning of dark adaptation. It does *not* reveal the change, in the retina or elsewhere, which makes possible the observed increase in the sensitivity of the system as a whole. Theories as to the nature of this change have not been lacking. Most prominent is the theory that the amount of rhodopsin increases and that the threshold is characterized, at all stages of adaptation, by the breakdown of a *constant minimal amount* of this photochemical substance. This form of analysis has been used with marked success in the interpretation of data on human thresholds during dark adaptation (**8, 16**). A moment's consideration will show, however, that the analysis cannot be directly applied to electrically recorded responses of the retina. The reason is that very high (4.5 log units above threshold) intensities of flash are necessary to arouse even minimal electrical responses. Hence it is to be expected that relatively large amounts of photosensitive substance must be broken down by each flash of light used in the electrical experiments. At the present state of our knowledge we have no reason to suppose that a 32,000-fold increase in stimulus intensity (going from absolute threshold to the flashes used to elicit minimal *B-waves*) will have the same effect when the eye is light adapted as when it is dark adapted. (This assumption is implicit in the treatment of Karpe and Tansley.) On the contrary, it seems reasonable to suppose that the relatively large amount of photosensitive substance available in the later stages of dark adaptation may favor electrical responses more than psychophysical thresholds. This supposition is in harmony with our results, as may be seen in Figs. 4-A, 4-B, and 4-C.

Riggs's (**14**) finding with the frog eye and Johnson's (**10**) with the human, to the effect that responses of the dark-adapted eye differ importantly in wave form from those of equal magnitude in the light-adapted eye, show clearly that there is no stimulus which, presented to the 100-min. dark-adapted eye, will produce a *B-wave* matching *any* response of the 1-min. dark-adapted eye. The dark-adapted responses have longer latencies and run a slower course in time. If the *B-wave*, as is generally believed, represents some phase of the neural activity of the retina, it is obvious that there are changes in the physiological organization during dark adaptation which cannot be readily related to the concentration of rhodopsin; and it seems hardly likely that the temporal characteristics of the *B-wave* are irrelevant while its magnitude remains in some way relevant to psychophysical functions.

The point we are making here may be clarified if we explain why one of us in a recent paper (**15**) used a correspondence between the electroretinal and psychophysical thresholds to argue *for* the scotopic identity of the *B-wave* while we now brush away the *lack* of correspondence apparent in the present paper as having no bearing on the question. In this paper (**15**) the relative sensitivity of the eye to various wave lengths of light was determined electrically (light to produce a *B-wave* of standard magnitude) and psychophysically (matching at low brightness). It should be noted that the eye was kept at a relatively *constant state* of adaptation. Although the "constant" electrical responses were described principally in terms of their magnitudes, they were also sufficiently similar in their other aspects (with minor exceptions in red responses) and could be accepted as representing equivalent responses of a physiologically stable system.

In conclusion, it is clear that the

B-amplitudes and any of several other measures of the electroretinal response are "measures" of dark adaptation in the sense that they represent definite changes which occur with regularity as the eye remains in the dark. We believe that these changes are significantly related to the increased sensitivity which the human scotopic visual system exhibits concurrently with their development. We do *not* look for a one-to-one agreement between any of these measures and the psychophysically determined absolute threshold.

Summary and Conclusions

Psychophysical procedures have been employed in experiments designed to match an earlier study of dark adaptation in which human electroretinal responses were used. The level of preadaptation was kept low enough to involve principally the scotopic system of the eye, since it was known that the retinal responses were primarily scotopic in origin. It was found that the extent of dark adaptation, measured as a lowering of the light intensity necessary to arouse a response, was roughly comparable in the absolute threshold experiments and in the electrical ones. The two sets of dark adaptation curves are not, and cannot be expected to be, identical. Their general similarity does, however, support the conclusion that human dark adaptation takes place largely at the retinal level, and that the scotopic visual system is responsible for the phenomena observed in both sets of experiments.

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RESPONSE EVOCATION ON SATIATED TRIALS IN THE T-MAZE

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The occurrence of a response in absence of the original drive under which it was acquired is a predominant problem in behavior theory. The theories set forth in explanation of such behavior may be classified into three categories.

1. *Nominal theories.*—In absence of the drive of acquisition, the response is elicited as an autonomous process. These theories are characterized by Allport's concept of "functional autonomy" (1).

2. *Irrelevant drive theory.*—In absence of the drive of acquisition, the response is elicited by the presence of other unreduced drives. This theory applies to only a restricted experimental design such as that of Webb (10).

3. *Acquired evocation property theories.*—These may be further subdivided into: (*a*) *Stimulus evocation theories*: In absence of the drive of acquisition, the response is elicited by the presence of the original stimulus context. This formulation is oriented in terms of the developed habit strength during original learning. Perhaps the most analogous theory is that of Hollingsworth's (4) Redintegration Theory and certain conditioning data. (*b*) *Acquired motive theories*: In absence of the drive of acquisition, the stimuli associated with the original drive acquire motivating properties which elicit the response. The evocation property is interpreted in terms of the reinstitution of the original drive state. These theories are typified by the work of Anderson (2) and Miller (6).

The present experiment presents data pertinent to the general problem and of particular interest to the last group of theories cited above. The data herein presented have specific bearing on two studies, one by Anderson (3), the other by Siegel (8), which involved the evocation of learned responses in satiated animals in the maze situation. The present study also has general significance for the work of Koch and Daniel (5), which was concerned with the evocation of learned responses in satiated animals in the Skinner Box. More specifically, the present data are concerned with the level of evocation of responses in the satiated condition as related to the rate of acquisition of the habit.

METHOD

The present data were collected as a part of a separate study, and a more detailed description of procedure may be obtained from that source (9). For the purposes of this paper, a brief summary will suffice.

Subjects and apparatus.—Eighty-four albino rats were used. Their ages varied from 90 days to 120 days. The apparatus was a single-unit, enclosed T-maze, with a 24-in. stem and 36-in. arms. There was a starting door, two doors at the choice point, and a pair of goal box doors. The running procedure was to have all doors except the choice point doors closed until *S* had been placed in the entrance compartment; when this was done, the starting box door was raised. After *S* had passed beyond one of the choice point doors, that door was closed and the goal

box was opened. The goal box door was closed as *S* entered the box. The food consisted of a .10-gm. pellet in a small circular dish in the reward box. Food and the food dish were placed on only one side for each *S*.

Motivational conditions.—In the larger experiment of which this represents a part, the *S*s were randomly divided into four groups and trained under drives of 1, 7, 15, and 22 hr. of food deprivation. Since analysis revealed no significant differences in the rate of learning or in performance on the "satiated" trials (see below), the data were combined for the four groups. All *S*s were placed on a 23-hr. feeding schedule for the last week prior to the start of the experiment. Every *S* was given a daily ration of 9 gm. of Purina Dog Chow. After 1 hr. the uneaten food was removed from the cage. At the beginning of the experiment, each *S* was given, instead of the 9-gm. ration, an unlimited amount of food during the 1-hr. feeding period. Water was available at all times.

Training procedure.—During the week of habituation to the feeding schedule, the *S*s were handled frequently in order to minimize their emotional responses to handling. At the end of a week, the *S*s were given a 30-min. exploratory period in the maze. They were then given four non-rewarded free choice trials to check for position habits; no *S*s were rejected on this basis (an arbitrary criterion of the choice of the same side on all four trials was used).

The actual training proceeded as follows. Every day, each *S* was given a series of four training trials, consisting of two free and two forced trials, i.e., if the *S* chose the reinforced side on each of the first two trials, he was then forced, by the closing of the proper choice point door, to the opposite side on the remaining two trials. Half of the *S*s were rewarded on the right and half on the left. This training procedure was followed for 14 days. In other words, the *S*s received a total of 56 training trials, half of which were free-choice and half of which were forced. Reinforcement was obtained on the correct side on half of the training trials. A minimum of 15 min. elapsed between the close of the day's training trials and the presentation of the daily food ration.

Satiation trials.—From the second day to the end of training, all *S*s immediately after feeding were given a series of two trials. Again one free and one forced trial were used. Neither the food dish nor the food was present on any of the trials run under the satiated condition. The *S*s were kept in a special running cage during all satiation and training trials and were not returned to the home cages until a minimum of 5 min. had elapsed after their daily run. Furthermore, the running order was systematically varied in order to eliminate possible tracking effects. All animals received a total of 26 satiation trials, of which 13 were free-choice.

Results

The results of this experiment are basically concerned with the adequacy of free choices made by the *S*s on the satiated trials. The percentages of correct responses, by days, are presented for both the satiated trials and the non-satiated training trials in Table I. The results recorded for the satiation trials are the percentages of responses made (on a single daily free-choice trial) to the side on which reinforcement was obtained during training. The results recorded for the training trials are the percentages of responses made (on two daily free-choice trials) to the reinforced side.

TABLE I

Total Group Response Data by Days on Satiated and Non-Satiated Trials ($n = 84$)

Day	Per Cent Correct on Training Trials (2 Trials per Day)	Per Cent Correct on Satiation Trials (1 Trial per Day)
1	49	—
2	64	70
3	69	76
4	79	79
5	85	83
6	87	83
7	89	90
8	96	88
9	95	95
10	96	93
11	99	92
12	99	94
13	100	99
14	100	98

Discussion

The present results are in striking opposition to those obtained by Koch and Daniel (5), who reported a reaction potential "strikingly close to zero" after satiation of the relevant

drive. They attributed the difference between their results and those of a number of earlier investigators to their own establishment of more complete satiation. Such an explanation does not, however, seem applicable to the present data for two reasons: First, although failure to achieve complete satiation could have conceivably resulted in the survival of a much reduced response tendency, it coule not have produced a reaction potential of the obtained magnitude; and, second, a study by Webb (11) has indicated that there is no significant difference between the satiation technique employed by Koch and Daniel and that used in the present investigation. A possible explanation of the existing discrepancy may lie in the differences in the tasks involved; difficulties arise, however, in attempting to define the pertinent differences. It is suggested that the contrast *between* the specific stimulus character of the maze and/or the similarity of the maze goal box to the running portion and the generalized environment of the Skinner Box may prove a pertinent hypothesis. Support for this point of view is afforded by the previous work of Perin (17) in which it was suggested that secondary reinforcement cues are minimized in the Skinner Box. If such be the case, the same would hold true for secondary motivation cues, and absence of the reward would have a relatively greater disruptive effect upon the habit in question. More complete definition of the pertinent differences between the maze situation and the Skinner Box awaits further research.

The present results are also at odds with those reported by Siegel (8), who used a four-unit T-maze and found that error scores remained at a "chance level throughout the satition trial series, while the drive trial series showed a regular decrement in error. . . ." Here one can only invoke a difference in complexity to which to attribute the existing discrepancies.

At the simplest level, the present data confirm the predictions of Anderson's externalization of drive theory, the essentials of which are set forth in the following quotations:

> . . . a drive such as hunger is originally aroused by internal conditions of the organism (e.g., hunger contractions) but that with continued usage the drive mechanism which leads to persistent and motivated behavior gradually becomes arousable by characteristics of the external situation, that is the drive becomes externalized. . . . once a drive has become externalized, i.e., arousable by various aspects of the external situation, the mere presentation of an appropriate part of the external situation will be adequate to arouse the drive and thus to improve performance (3, p. 349).

An important prediction can be made from the above hypothesis. It can be assumed that, after the animals have received a number of reinforcements, external factors will acquire performance elicitation strength; removal of the need state by satiation will leave external factors operative. "Drive behavior as a function of these . . . factors should increase with learning, and the error score during interposed satiation trials should undergo a progressive decrement" (3, p. 145). The applicability of this prediction to the present study is immediately apparent upon examination of Table I, which shows that the error score during interposed satiation trials actually did undergo a progressive decrement and, as a matter of fact, paralleled closely the error score obtained on the learning trials.

The surprising character of these data is in this extremely close parallel of the evocation and learning curves. Surely, one would not expect the evocation curve to be higher than the

learning curve, for this would indicate that learning was greater under no drive than under a relevant drive; however, one might readily hypothesize that the evocation curve would be lower, particularly during the early phases of training. The data herein presented, however, indicate that the external environment can, and in this case *did*, acquire evocation properties at a much more rapid rate than had previously been expected.

In summary, the present study, in the opinion of the authors, emphasizes the intimate relationship between the acquisition and development of the habit *and* its evocation in the absence of the relevant drive. The existence of this intimate association between the habit strength development and the evoked response in the absence of drive tends to favor an interpretation of the data in terms of the stimulus evocation theories cited above.

The wide divergence between the results herein presented and those of several earlier investigations (**5, 8**) raises the question of the nature of the stimulus complex which will acquire evocation (motivational) properties rapidly and in great strength; only further research will yield more adequate definitions of the pertinent variables.

Summary and Conclusions

This experiment was designed to find out if a learned response continues to be made after satiation of the relevant drive under which it is being or has been developed. The *Ss* of the experiment were 84 albino rats, ranging in age from 90 to 120 days. All *Ss* were trained in a single-unit T-maze, with food designating the correct side. They were given four training trials daily; furthermore, they were run each day immediately after feeding, to check on the strength of the habit in the absence of the relevant drive. Forced trials were employed to make sure that all *Ss* ran an equal number of trials to both the correct and incorrect sides of the maze.

A comparison of the per cent of correct responses on the satiation and training trials reveals that satiation of the relevant drive had little or no detrimental effect upon the continued performance of the learned response. The extremely close parallelism of the evocation and learning curves indicates that the external environment can acquire evocation properties at a much more rapid rate than had previously been expected. The obtained results, because of their magnitude, are interpreted as confirming Anderson's hypothesis of the "externalization of drive," but favoring an interpretation oriented toward role of habit as the mediating mechanism rather than emphasis on the "acquired drive." However, the problem of defining the nature of the stimulus complex which will acquire evocation (motivational) properties rapidly and in great strength remains to be solved.

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COLOR ADAPTATION UNDER CONDITIONS OF HOMOGENEOUS VISUAL STIMULATION (*GANZFELD*)

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Gestalt theory assumes that the arousal of articulated perceptual processes depends upon inhomogeneous stimulus distributions on the sensory surface (4, 5). Thus, to Koffka (4, p. 110), the "simplest" visual percepts are occasioned not by punctiform stimulation of a single rod or cone, but by distributions of retinal stimulation which approach complete uniformity. Although investigations of the effects of such homogeneous distributions would seem important in understanding organization under more complex circumstances (and in approaching such problems as the formation of three-dimensional perceptual space, the segregation of the "Ego," etc.), the research done in these areas since the pioneer investigations of Metzger (6) has been meager. This paper describes a comparatively simple method for approximating the required visual stimulus conditions, and reports the perceptual responses obtained in exploratory experimentation on the effects of spatially homogeneous chromogenic stimulation.

Metzger had his observers sit 1.25 m. from a whitewashed wall equipped with wings attached at all four edges with a minimum of inhomogeneity so as to fill the *S*'s field of view. When the intensity of illumination was sufficiently low, imperfect accommodation blurred the slight textural inhomogeneities of the wall so that the stimulus distribution was so homogeneous that the Ss perceived a space-filling, surfaceless fog. This finding offers support for Koffka's hypothesis that homogeneous illumination of the retina does not provide the differentiation necessary to maintain a surface as a structure in the visual field (4, p. 117). With increased illumination and, presumably, improved accommodation, the texture of the wall provided sufficient inhomogeneity to institute the perception of a surface through an interesting and significant series of transition stages.

Koffka makes a further prediction, which has not yet been tested, concerning the response to homogeneous visual stimulation. Since the Gestalt explanation of color constancy (and of "framework" phenomena in general) requires that the "general background . . . will appear as neutral as the conditions will allow" (4, p. 256), Koffka predicts (4, p. 121) that a perfectly homogeneous field of colored light will appear neutral rather than colored as soon as the *S* relinquishes the "framework" carried over from his previous environment.[1] Since the Hering theory of color vision predicts that continued stimulation of color receptors should ultimately result in sensations of middle gray, there have been a number of studies of color adaptation under prolonged stimulation; their results, as reviewed by Helson and Judd (3),

[1] In fact, with ideal homogeneity (involving uniform distributions in all modalities) perhaps the *S* will perceive *nothing at all* (4, p. 120), although, due to the status of the "Ego" in the Gestalt conception of the perceptual field (4, p. 113), Koffka expects (4, p. 121) that the disappearance of color may be attended by a change in the "mood" of the *S*.

indicate that disappearance of color takes place only under very special circumstances. Thus, Helson and Judd had their *Ss* place their heads in a 36-in.-diameter sphere lined with Hering orange-red paper under "very intense" illumination (to hasten any adaptation effects as might occur). They report that "at no time, not even after 75 min. adaptation, did the color of the surface viewed completely and permanently disappear. The equilibrium condition with its associated neutral gray demanded by the Hering theory under conditions of constant retinal stimulation failed to appear" (3, p. 386). They were, however, able to get "fairly good grays" maintained for very short periods of time with fixation of the eyes, and concluded that *eye-movements alone, even with homogeneity of retinal stimulation*, will destroy adaptation. It should be noted, however, that these color adaptation studies (and the more recent investigations of Wright [8]) were not performed under conditions of complete homogeneity of stimulation over the entire retina. Even the conditions used by Helson and Judd undoubtedly retained sufficient textural inhomogeneity to allow the perception of a surface color, since the distance of the surface allowed fixation and accommodation. They do not constitute adequate test of Koffka's hypothesis, therefore, and repetition under more homogeneous stimulus conditions is in order.

The experiments here reported constitute an exploratory study of the percepts obtained under spatially homogeneous colored illumination over the entire visual field.[2] Specifically investigated were (1) whether fields of colored illumination of sufficient homogeneity to be perceived as surfaceless fog will lose their color and become chromatically neutral; and whether the effects upon any such chromatic adaptation of (2) separate adaptation of each eye, (3) the introduction of an inhomogeneity (here, a shadow) into the field, (4) eye movements, and (5) interruption of the illumination after adaptation, are in accordance with what would be expected from Koffka's hypothesis and/or with the results obtained by Helson and Judd under conditions of less complete homogeneity.

Apparatus

The apparatus used consisted of two eyecaps, made from halved table-tennis balls of heavy material and good diffusing power, carved to fit over the eyes and eyelids with snug contact around the edges. In these experiments, a light coating of a nonirritating, easily removed, latex-based surgical adhesive applied around the eye socket and to the edges of the eyecaps assured a strong support and light-seal. Since in most cases the *S*'s eyelashes are so long as to disturb both the homogeneity of stimulation and his own comfort, the upper eyelashes were temporarily fastened to the upper eyelids with a small quantity of the same adhesive before applying the eyecaps.

This apparatus was designed and constructed in preference to that used by Metzger (2, 6) because of what the authors believe to be inherently superior characteristics:[3] (1) The nose and cheekbones, etc., are not included in the visual field, yet there is no narrowing of the field of view. (2) The diffusing surfaces of the eyecaps are within the minimum accommodation distance for all *Ss* used. (3) The intensity of the incident light can be varied at will without introducing the textural cues of illumination. (4) The eyecaps in no way encumber the *S*, and

[2] Other work with modified forms of this device is under way at Cornell University in connection with a research project on the effective stimuli for space perception supported by the United States Air Force and directed by Prof. J. J. Gibson; with further studies in color adaptation; and with an investigation of the personality-determined aspects of perception under homogeneous stimulation.

[3] The expedient of using the halves of a table-tennis ball for this purpose had apparently been developed independently by Dr. R. S. Harper of Knox College.

there is complete flexibility with respect to movement (a consideration of no weight in this study, but vital to several projected studies). (5) The savings in construction expense and laboratory space are considerable.

The light was projected from 100-w. Kodaslide Model 2a projectors, either through a red Wratten filter No. 70 in B glass, or through a green filter, No. 54. The distance between projector lens and eyecaps of the *S* was 9 ft. 3 in. and *S*'s head was held in a headrest with attached side reflectors of white cardboard in order to attain approximately equal illumination on the front and sides of the eyecaps.

Results

Experiment A.—The purpose of this experiment was to determine whether a homogeneous field of either red or green light will become chromatically neutral after prolonged inspection. Eleven *Ss* who were instructed to report continuously on shape, distance, color, texture, and any changes which might occur were divided into two groups.

In Group A1 ($N = 6$), light was projected through the red filter upon both eyecaps. An arbitrary limit of 20 min. was set as the time within which color disappearance was to be obtained. Five of the six *Ss* initially reported a red-colored surfaceless field followed by the total disappearance of the color within the first 3 min. The remaining *S* reported a cone-shaped three-dimensional surface, concave towards himself, whose color even after prolonged adaptation (20 min.) remained a "very dark, brownish magenta." This was accompanied by considerable anxiety and a strong desire to "put his hands into" the extended form he saw before him.[4] Of the other five *Ss*, one reported a dull ivory as the stable adapted field, and the description of the adapted field by the remaining four *Ss* varied from a deep black (or a feeling of having gone blind) to that of a dark gray sensation. The course of adaptation consisted of a darkening of the field, both by a desaturation of the red by admixture of black or dark gray, and by encroaching regions of black or dark gray, frequently taking the form of fanciful or threatening shapes.

In Group A2 ($N = 5$), light was projected through the green filter upon both eyecaps, the procedure otherwise being the same as for Group A1. In Group A2, all five *Ss* initially reported a green surfaceless field followed within a maximum of 6 min. by total disappearance of green. In this group, the adapted field ranged from black (or "nothingness") to dark gray. One of the *Ss* reported a flight of colors before the final state of adaptation (here, dark gray) appeared. The other *Ss* reported desaturation of the green by gray and blue before the final disappearance of color.

Three *Ss* in Group A1 and two *Ss* in Group A2 reported the appearance of "hallucinatory" shapes or objects at some time during the course of adaptation, and two of the *Ss* in Group A1 were hard to convince afterwards that such shapes had not actually been introduced as part of the experimental procedure. All *Ss* were firm in their belief that the illumination had at least been changed in some manner during the session.

Only one of the 11 *Ss* in Groups A1 and A2 reported a surface. The remainder of the *Ss* reported what

[4] Whether any relationships exist between personality factors, the mode in which the *Ganzfeld* is perceived, and the course of color adaptation, is yet to be investigated. However, the indeterminacy and true lack of structure in this situation, the individual differences in hallucinatory objects and patterns perceived during the course of adaptation, and the intense fear and feelings of "going blind" expressed by some of the *Ss* suggest a possible method for investigation of personality structure.

may be subsumed under the term "fog" or "cloud." All of the *Ss* who did not see a surface experienced a stable, well-defined disappearance of the color, and many of these were unwilling to believe that the lights had not been changed or shut off. These results are more in accordance with Koffka's prediction than were those obtained in the situation employed by Helson and Judd. In agreement with the findings of Helson and Judd, and against what would be expected from Hering's theory, the color reported after adaptation was not mid-gray, but was generally inclined towards dark gray or black.

Experiment B.—The purpose of this experiment was to determine the effects of separate adaptation by each eye. In Group B1 ($N = 5$), the right eyecap was covered by a shield mounted on the table between the projector and the *S*, and the left eyecap was exposed to red light until the *S* reported all color gone from the field. After this, the shield was removed without interrupting the light reaching the left eyecap, and the right eyecap was thus also illuminated. All five *Ss* reported a red sensation appearing as the right (unadapted) eye was first stimulated. Three of the *Ss* localized the red sensation as coming from the *right eye alone, the left eye remaining black.*

In Group B2 ($N = 5$), in which the same procedure was used with green light rather than red, the results obtained were of the same nature as those found in Group B1: when the right eye was exposed to the same light to which the left eye had already been adapted, all five *Ss* reported a strong green sensation, and four of them identified it as appearing in the *right eye alone, the left eye remaining black.*

In general, the results of adaptation of the left eye in Groups B1 and B2 supported the findings of Experiment A. One *S* in Group B1 reported deep brown as the final adaptation state, and one *S* in Group B2 reported varicolored spots in the final adapted field; the remaining eight *Ss* reported "nothingness," complete blackness, dark gray, or a suspicion that the lights had been turned off. In both groups, B1 and B2, disappearance of color was finally achieved in the right eye as well, although not as satisfactorily as it was with simultaneous adaptation of both eyes, or of one eye alone.

If such an adaptation process (or, in terms of Koffka's hypothesis, the disappearance of color because of its becoming what might be termed the "chromatic neutral point") took place at any neurological level past that at which binocular fusion occurs, the adaptation state should hold for the visual field in general, and not be confined to the eye which had been exposed to the light. The results of Experiment B suggest, on the contrary, that the adaptation process is restricted to the exposed eye, a finding more indicative of relatively peripheral than central processes.

Experiment C.—The purpose of this experiment was to determine the effects of introducing a shadow into a homogeneous field after adaptation. After the *Ss* in Groups A1 and A2 had reported disappearance of the color, the shadow of a finger was cast vertically upon the central region of their eyecaps in such fashion as to provide a shadowed portion in the adapted field, but not to shadow the entire field. In Group A1, in which the incident light was red, all five *Ss* reported a black shadow surrounded by a red halo, and both the shadow

and the halo quickly disappeared with the removal of the finger. In Group A2, in which the incident light was green, four of the five *S*s reported a black shadow against a green background or halo. The remaining *S* in this group reported a purple shadow against a green halo.

No new reference point has been provided in the *chromatic* series with the introduction of a shadow into the homogeneous adapted field. We would expect, according to the hypothesis of a "chromatic neutral point," that if the shadow were seen, it would be black against an achromatic, lighter background. The only way in which the shadow would seem capable of providing a chromatic reference point would be by the appearance of the complementary color in the shadowed region, a phenomenon obtained with only one *S* out of ten.

Experiment D.—The purpose of this experiment was to determine the effects of eye movements on the adapted field. After the *S*s of Group A1 had reported the results of Experiment C and after the *S*s of Group B1 had reported the disappearance of color from their left eyes, they were asked to move their eyes briskly from left to right, then back again. This was done eight times. Of the ten *S*s achieving complete color disappearance in Groups A1 and B1, five reported no re-appearance of color due to deliberate eye movements. The other five *S*s reported a quickly-fading flash of red. In four of these *S*s the flash of red was preceded by a flash of blue-green while the eye was in motion, and the intensity and duration of the red flash decreased with each repetition of the eye movements. After the fourth eye movement, two of these *S*s reported no further recurrence of color after eye movement for that or for the four subsequent eye movements. Furthermore, it seems reasonable to assume that at least minor eye movements were continuously occurring even in the absence of instructions calling for deliberate eye movements, since there was no possible fixation upon any point in the field; nevertheless, most of the *S*s in Experiments A and B reported disappearance of color.

Thus, eye movements here had only a limited ability to restore the vanished color, as contrasted with the important part they played in the situation reported by Helson and Judd. Because of four *S*s' report of the complementary color during eye movements, it would appear possible that the effects of such movements are a special case of the effect discussed below, and are due to a change of retinal illumination accompanying eye movement.

Experiment E.—The purpose of this experiment was to determine the effect of interrupting the homogeneous chromogenic stimulation to which the *S* has become adapted. After Groups A1 and B1 had reported the results of Experiment D, the ten *S*s who had achieved complete disappearance of color were subjected to interruption of the red light for intervals of approximately 2 sec., and were asked to report whether any change in sensation had occurred. While brief blinking during and after adaptation had no apparent effects (even under instructions to pay attention to the blinking), closing the eyes or interrupting the red light at its source for intervals of approximately 2 sec. elicited the complementary color, blue-green, for nine of the *S*s. Re-establishment of the stimulation resulted in a very brief flash of red for

these *Ss*. Only one of the *Ss* in Group A1 reported no effect consequent either to interruption or restoration of the illumination, continuing to report "nothingness."

These findings are in contradiction to those obtained by Helson and Judd (**3**, p. 393), who report that continued stimulation with saturated "colored" light (their *Ss* here wore spectacles which, it should be noted, permitted articulated spatial perception) did not result in the arousal of the complementary color as afterimage if the retina was kept in total darkness. The appearance of the complementary color when *homogeneous* stimulation is interrupted, as occurred in the experiment here reported, would seem to contraindicate attempts to explain the disappearance of color by assuming that the adapted receptors simply stop responding to the impinging chromogenic light. If the latter were the case, the *Ss* should also report the complementary color while the lights are still on, because the response occasioned by the failure of the adapted receptors to react to light should not be different, by this explanation, from the response occasioned by cessation of illumination of those receptors. Attempts at explanation might be made either by assuming that continued stimulation with light of a given color somehow *inhibits* neural impulses from receptors sensitive to the complementary wave lengths (**1**), *even though the receptors* (or *ganglia*) *sensitive to the impinging light may not themselves be responding any longer*, or by assuming that the receptors sensitive to the impinging light are exhausted until they reach an equilibrium condition of activity which *just balances* (**7**) the entoptic level of the other, relatively unaffected, receptors. Any attempt at the purely retinal explanation would, however, leave unexplained the fact that most *Ss* in Experiment C reported that the shadow, introduced into the field after color had disappeared, was seen as "black," not as the complementary color. The complementary appeared only when the entire retina ceased receiving chromogenic stimulation, as in Experiment E.

Summary

A technique is described whereby spatially homogeneous illumination may be presented to the eye, and the results of some exploratory experiments, using homogeneous colored light, are presented. Koffka's hypothesis that a colored *Ganzfeld* would lose its color was tested with red and with green light. Complete disappearance of color was obtained, in most cases, despite considerable individual differences in the course of the adaptation process and in the phenomenal content during adaptation. However, the results of presenting colored light to one eye after the other eye had been adapted to light of the same color, and of introducing a shadow into the field, make it difficult to ascribe the disappearance of the color to its adoption as a general "chromatic neutral point" for the entire visual field.

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